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(Cont over pag 3)

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Biomechanics Laboratory Department of Orthopaedics University of Gothenburg Sweden and the Biomechanics Unit of the Department of Mechanical Engineering Imperial College of Science and Technology London England

IN VITRO DIFFUSION OF DYE THROUGH THE END PLATES AND THE ANNULUS FIBROSUS OF HUMAN LUMBAR INTER VERTEBRAL DISCS

A NACHEMSON T LEWIN A MAROUDAS & M A R FREEMAN

Received 13 iv 1970

The nutritional pathways into the nucleus pulposus of human inter vertebral discs have aroused interest since histological examination de monstrated the lack of a direct vascular supply after the age of 25 years (Bohmig 1930 Schmorl 1930 Übermuth 1930 Coventry Ghorm ley & Kernohan 1945 Hirsch & Schajowicz 1952) It has been postu lated that diffusion through the end plates is the main nutritional route a postulate confirmed in the adolescent rabbit by the finding that this structure is permeable (Brodin 1955 Hansen 1959) These authors suggested that the annulus fibrosus might also be a nutritional route but of minor significance On the other hand recent studies suggest that the nutrition of adult (but not adolescent) articular cartilage depends entirely or almost entirely on the transsynovial route since the calci fied zone of the cartilage constitutes a virtually impermeable barrier (Collins 1949 Mankin 1963 Stockwell & Barnett 1964 Maroudas 1968 Maroudas Bullough Swanson & Freeman 1968 McKibbin & Holds worth 1968) It thus seemed possible that the end plates of the discs where a calcified zone is present (Coventry Ghormley & Kernohan 1945 Eckert & Decker 1957) might also be impermeable and that hence no nutritional route might be open through them Although the bone/cartilage interface or the calcified zone of the cartilage appears to present an impermeable barrier to the passage of nutrients from blood vessels in the bone to the cartilage this barrier is not always present Thus in animals and man before skeletal maturity vessels are in con

Table 1 The investigated material

Spine no	Age	Sex	Main cause of death	No of days before postmortem (+2 C)	No of days between postmortem and test (− 20 C)	Discs tested	Macroscopic exam of deg Grade 0 3
1	83	♀	*Circul insuff* Cardiosclerosis	2	14	L3	3
						L4	3
2	75	♀	Cardiosclerosis Cerebral hemorrh	1	1	L3	2
						L4	2
3	74	♀	Myocardial infarct	3	2	L2	3
						L3	3
4	69	♀	Pancreatitis	1	5	L3	3
						L4	3
5	68	♀	Pulmonary embolism	7	4	L3	3
						L4	3
6	64	♀	*Malign brain* tumor	1	3	L3	3
						L4	3
7	62	♀	Skull fractures	2	21	L3	3
						L4	3
8	53	♂	Circul insuff Cardiosclerosis	3	0	L3	1
						L4	3
9	52	♀	Ca *recti*	1	1	L3	2
						L4	3
10	47	♂	Cerebral contusion	2	2	L3	2
						L4	2

tact with cartilage at the endochondral ossification front and the bone cartilage interface is permeable in adolescent cadaver specimens in man (Maroudas, Bullough, Swanson & Freeman 1968). In adult man localized communications exist between the medullary cavity and the articular cartilage in certain joint surfaces. They are present, for example, in the femoral head but not in the acetabulum (Greenwald & Haynes 1969) and not (by inference) in the femoral condyles (Maroudas, Bullough, Swanson & Freeman 1968). The nutritional significance of these communications is uncertain.

Keyes & Compere (1932) and Coventry et al. (1945) thought that degenerative changes of the disc were responsible for back pain. It is perhaps fair to summarize the present view by saying that disc degeneration is thought to be capable of producing back pain and sciatica although the exact mechanism of pain production and the precise relationship between the morbid anatomy and the symptomatology are uncertain. Disc degeneration is characterized histologically by loss of tissue in the nucleus, increasing thickness of the collagen fibres and the occurrence of fissures both in the centre and in the periphery of the disc. Insufficient diffusion into the disc has been said to account for premature disc degeneration (Bohmig 1930, Schmorl 1930, Übermuth 1930).

In a study of the pH of discs of patients operated upon for lumbar rhizopathy, a marked decrease of pH was noted in some discs (Nachemson 1969). These cases also showed an abundance of connective tissue scarring around the nerve roots. In other subjects in the same study the pH of both normal and prolapsed discs varied between 6.5 and 7.4 with a lower value for those discs showing degenerative changes on ordinary radiographs. A number of mechanisms could have caused this increase in hydrogen ion concentration, but a separate study demonstrated that the main factor was probably an increased concentration of lactic acid, the concentration of which was found to be directly correlated with the hydrogen ion concentration of the nucleus (Diamant et al. 1968). Lactic acid is always present when intermediate carbohydrate metabolism is proceeding under anaerobic conditions and thus it might be inferred that oxygenation of and hence diffusion into the acidotic discs was impaired.

In view of these findings, the present study was performed (1) to examine diffusion into the nucleus through the end plates and the annulus fibrosus and (2) to test the possibility that in some cases one or the other of these routes was blocked.

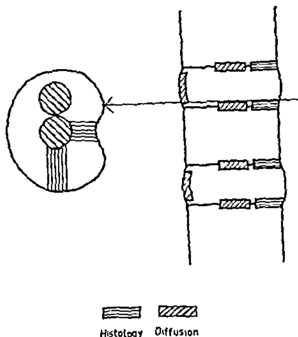


Figure 1 Drawing showing the sites from which specimens were taken for diffusion and histological studies

MATERIAL AND METHODS

This study was designed to investigate qualitatively the diffusion of the dye disulphine blue V through the annulus fibrosus and the upper and lower end plates of human cadaver lumbar discs This dye was chosen because it diffuses readily through articular cartilage *without* showing specific interactions with it.

The discs between the third and fourth (the L_3 disc) and the fourth and fifth (the L_4 disc) lumbar vertebrae from post mortem specimens were used A total of 33 discs (6 end pl tes) from 19 individuals *representing* at least four different discs from each decade were studied (*Table 1*) The material was collected imme d ately after post *mortem and* stored at —20 C. As seen from Table 1 the number of days between death and post *mortem* examination varied between 1 and 7 (mean days)

Lateral and frontal radiographs were taken *of the* spines to exclude pathological changes in the vertebral bodies *and* also to obtain a rough estimate *of the* state of the discs. S nce the *discs* were also *examined* macroscopically (a more reliable method of asses ing their cond tion accord ng to Friberg & H rsch 1930) the evaluation of the radi *graphs* has not been included *in* Table 1 The spines were then cleansed of mu cles and ligaments and the discs L_3 and L_4 w re removed through cuts in the adjacent vertebral *bodies*

The anterior *portion of* the annulus fibrosus was then removed and the disc

Table 1 The investigated material (cont)

Spine no	Age	Sex	Main cause of death	No of days before postmortem (+2 C)	No of days between postmortem and test (—20 C)	Discs tested	Macroscopic exam of deg Grade 0–3
11	44	♂	Ca ventriculi	2	7	L3	2
						L4	2
12	34	♂	Hepatic rupture	1	8	L3	2
						L4	3
13	33	♀	Intrapleural hemorrhage	1	3	L3	1
						L2	1
14	24	♀	Drug intox	3	3	L3	1
						L4	1
15	22	♂	Ethyl intox	4	4	L3	1
						L4	1
16	18	♂	Skull fractures	3	1	L3	1
						L4	1
17	11	♀	Pulmonary embolism	3	2	L3	0
						L4	0
18	5	♀	Cerebral hemorrhage	4	4	L3	0
						L4	0
19	0	♂	Pneumonia	3	0	L4	0
						L5	0

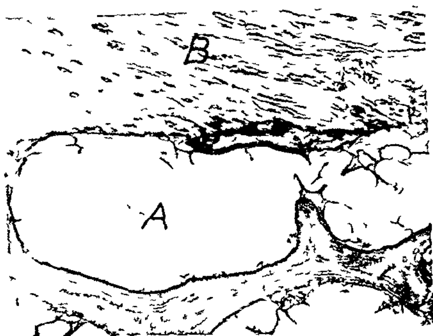


Figure 3a Lateral portion of vertebra with wide ampulla like contact between medullary cavity (A) and end plate cartilage (B) Case 5 Ag 68

ber described by Maroudas et al. (1969) In order to prevent leakage round the edge of the specimen the specimen was fitted with rubber washers on the bony side before being clamped in the diffusion cell One compartment of the diffusion cell was filled with 10 ml of Ringer's solution and 10 ml of 2% disulphine blue dye in Ringer solution was added to the other compartment (Figure 2) The appearance of the dye was noted in the first compartment as it diffused through the specimen The area of the specimen exposed to the dye was 35 mm² (Figure 2) The dye solution was always placed in contact with the vertebral side of the end plate The diffusion experiments lasted 24 hours and were conducted at +4 C If at the end of this time no dye was seen to have penetrated the specimen the experiment was continued for a further 24 hours

Since this study was designed to be purely qualitative no attempt was made to measure the amount of dye which penetrated the preparations The results were regarded as positive if dye traversed the specimen so as to be visible in the Ringer's solution on the other side of the diffusion chamber and as negative if no dye penetrated after 48 hours

After completion of the diffusion experiment the end plates were sectioned for naked eye inspection and for histological examination For the latter the specimens were fixed in 10% formaldehyde solution and then decalcified in a mixture of equal volumes of concentrated formic acid and 7% sodium formate solution Each decalcified specimen was embedded in paraffin and 3–4 sections approximately 10 μ

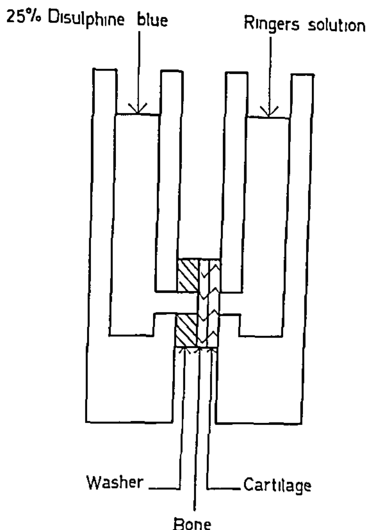


Figure 2 Drawing showing the construction of the diffusion cell

was sectioned horizontally through its centre and photographed On the cut disc the degree of degeneration was evaluated on a 0–3 scale according to the criteria used earlier by among others Friberg & Hirsch (1950) Nachemson (1960) and Galante (1967)

Sections were prepared for diffusion by removing the soft material of the nucleus pulposus down to the cartilaginous end plate taking care to avoid damage of the cartilage itself Circular specimens with a diameter of 10 mm were then cut with a special tool from the middle and lateral portions of the upper and lower end plates (Figure 1) The vertebral part was ground with sandpaper almost down to the subchondral bone plate The final thickness of the specimen varied from 3 to 4 mm

The annulus fibrosus was sliced vertically to produce a specimen whose thickness varied from 2 to 3 mm

The prepared specimens were placed in the specially constructed diffusion cham

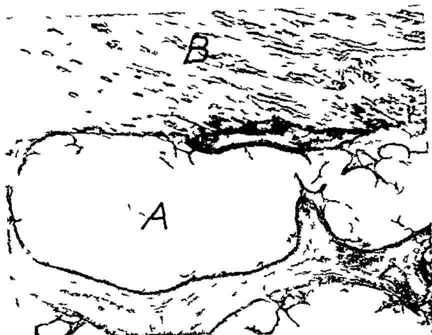


Figure 3 a Lateral portion of vertebra with wide ampulla like contact between medullary cavity (A) and end plate cartilage (B) Case 5 Age 68

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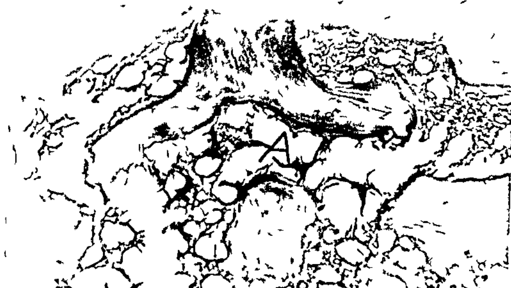


Figure 1b Central portion of vertebra with wide ampulla like contact between medullary cavity (A) and end plate cartilage (B) Case 12 Age 35

thick were cut from it on every second millimeter on a standard microtome In this fashion a representative histological sample of the total specimen could be obtained

In every lateral specimen the histological appearance of the end plate was judged from a section immediately adjacent to the specimen prepared for diffusion (Figure 1) In addition 10 of the central specimens subjected to diffusion experiments were themselves subsequently prepared for histological examination In all 72 end plates from 18 individuals were examined histologically Due to technical difficulties 6 end plates were omitted from this part of the study (cases 4 12 14)

The histological status of the end plates was grouped on a 0 to 3 scale (Lenin 1964) as follows

Grade 0 Hyaline end plate cartilage without any degenerative changes Smooth subchondral bone plates

Grade 1 Minimal changes in the cartilage such as cell proliferation and/or paucity of cells with or without minor cartilage necrosis

Grade 2 Necrosis of cartilage and the beginning of co[illegible] with from the subchondral bone which shows sclerosis and/

Grade 3 Cartilage completely destroyed in many connective tissue Advanced subchondral remodelin

Special note was made of the existence of th cartilage and the medullary cavity as demonstrate

The histological investigation was performed without knowledge of the results of the diffusion experiments

RESULTS

Overall results

The overall results are presented in Table 2 It can be seen that in almost all cases the central portion of the end plates was permeable Thus the upper central portion was permeable in 33 of 38 studied end plates of the L_3 and L_4 discs In the central part of their lower end plates permeability was seen in 33 of 37 examined The annulus fibrosus was also usually permeable 27 specimens were permeable only 5 were impermeable In contrast the lateral part of the end plate was usually impermeable Thus the upper as well as the lower lateral portion of 36 end plates of the L_3 and L_4 discs was impermeable in 27 specimens

The measurements of permeability on the annulus are particularly exposed to the criticism that the exact thickness of the specimen was not measured The apparently impermeable specimens may therefore have been the thickest so that the dye did not have time to traverse the whole specimen Since inspection of the impermeable specimens revealed the presence of dye in the annulus and since the annulus does not contain any structure comparable to the calcified zone of cartilage which might arrest the movement of dye within the thickness of the structure eventual penetration of the annulus even in the apparently impermeable specimens would seem to have been inevitable In contrast in the impermeable end plate specimens the dye was found to be sharply held up at the calcified zone

Histological studies

The following general observations should first be stressed The microscopical picture of the bony end plate and the hyaline cartilage plate fits well into the earlier observations by Bohmig (1930) Schajowicz (1938) and Coventry Ghormley & Kernohan (1945) up to age 25–30 years The same holds true regarding the picture of degenerative changes in all ages In the histological appearance of the bony end plate after age 30 however we found that earlier investigations have not taken into consideration the existence of communications between the

We could not reproduce a photograph here because black and white did not show the features we described and a colour reproduction was too expensive

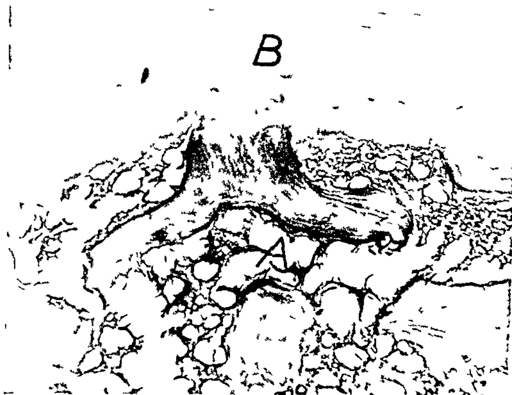


Figure 3 b. Central portion of vertebra with wide ampulla-like contact between medullary cavity (A) and end plate cartilage (B). Case 12. Age 34.

thick were cut from it on every second millimeter on a standard microtome. In this fashion a representative histological sample of the total specimen could be obtained.

In every lateral specimen the histological appearance of the end plate was judged from a section immediately adjacent to the specimen prepared for diffusion (Figure 1). In addition, 10 of the central specimens subjected to diffusion experiments were themselves subsequently prepared for histological examination. In all 72 end plates from 18 individuals were examined histologically. Due to technical difficulties 6 end plates were omitted from this part of the study (cases 4, 12, 14).

The histological status of the end plates was grouped on a 0 to 3 scale (Lewin 1964) as follows:

Grade 0. Hyaline end plate cartilage without any degenerative changes. Smooth subchondral bone plates.

Grade 1. Minimal changes in the cartilage, such as cell proliferation and/or paucity of cells with or without minor cartilage necrosis.

Grade 2. Necrosis of cartilage and the beginning of connective tissue ingrowth from the subchondral bone which shows sclerosis and/or atrophy.

Grade 3. Cartilage completely destroyed in many areas where it is replaced by connective tissue. Advanced subchondral remodeling.

Special note was made of the existence of the contact between the end plate cartilage and the medullary cavity as demonstrated in Figure 3.

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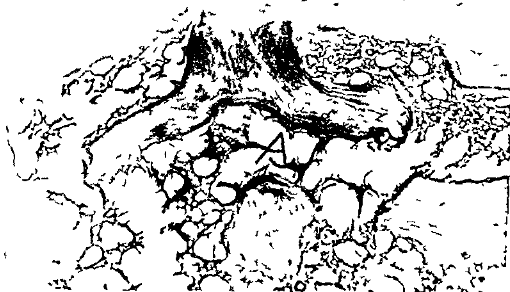


Figure 3 b Central portion of vertebra with wide ampulla like contact between medullary cavity (A) and end plate cartilage (B) Case 1? Age 31

thick were cut from it on every second millimeter on a standard microtome In this fashion a representative histological sample of the total specimen could be obtained

In every lateral specimen the histological appearance of the end plate was judged from a section immediately adjacent to the specimen prepared for diffusion (Figure 1) In addition 10 of the central specimens subjected to diffusion experiments were themselves subsequently prepared for histological examination In all 72 end plates from 18 individuals were examined histologically Due to technical difficulties 6 end plates were omitted from this part of the study (cases 4 12 14)

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Grade 1 Minimal changes in the cartilage such as cell proliferation and/or paucity of cells with or without minor cartilage necrosis

Grade 2 Necrosis of cartilage and the beginning of connective tissue in growth from the subchondral bone which shows sclerosis and or atrophy

Grade 3 Cartilage completely destroyed in many areas where it is replaced by connective tissue Advanced subchondral remodeling

Special note was made of the existence of the contact between the end plate cartilage and the medullary cavity as demonstrated in Figure 3

experiments and anatomic studies

Annulus ventral part	Macrosc exam. of disc deg Grade 0–3	Microsc exam of deg Grade 0–3	Vascular buds observed Upper central	Upper lateral	Lower central	Lower lateral
—	3	1–3	×	—	×	—
not perf	3	1–3	×	—	×	—
—	2	0–2	×	—	×	—
—	2	0–2	×	—	×	—
+	3	0–2	×	—	×	—
+	3	0–2	×	—	×	+
+	3	Not available				
+	3	Not available				
+	3	2 3	×	—	×	+
+	3	2 3	×	+	×	+
+	3	1–3	×	+	×	—
+	3	0 3	×	—	×	+
+	3	1–3	×	+	×	—
+	3	1–3	×	—	×	—
	1	1–2	×	+	×	+
–	3	1–2	×	—	×	—
+	2	0	×	+	×	+
not perf	3	0	×	—	×	—
+	2	0	×	+	×	—
+	2	0	×	+	×	—
not perf	2	0	×	+	×	—
not perf		0	×	+	×	—
+	2	1 3	+	×	+	×
+	3	1–3	+	×	+	×
–	1	1	×	—	×	—
+	1	1	×	—	×	—
+	1	1	+	×	+	×
+	1	1	+	×	+	×
–	1	0	×	—	×	—
+	1	0	×	—	×	—
+	1	0	+	—	+	—
+	1	0	+	—	+	—

Table 2 Results of diffusio

Spine no	Age years	Disc	End plate			
			Upper central	Upper lateral	Lower central	Lower lateral
1	83	L3	+	—	—	—
		L4	+	—	—	—
2	75	L3	+	—	+	—
		L4	+	—	+	—
3	74	L2	+	—	+	—
		L3	+	—	+	+
4	69	L3	+	—	+	—
		L4	+	—	+	—
5	68	L3	+	—	+	+
		L4	+	+	+	+
6	64	L3	+	+	+	—
		L4	+	—	+	+
7	62	L3	+	+	—	—
		L4	—	—	not perf	—
8	53	L3	+	+	+	+
		L4	+	—	+	—
9	52	L3	+	+	+	+
		L4	—	—	—	—
10	47	L3	+	—	+	—
		L4	—	+	+	—
11	44	L3	+	+	+	—
		L4	+	+	+	—
12	34	L3	+	—	+	—
		L4	+	+	+	+
13	33	L3	—	—	+	—
		L2	—	—	+	—
14	24	L3	+	—	+	—
		L4	+	—	+	—
15	22	L3	+	—	+	—
		L4	+	—	+	—
16	18	L3	+	—	+	—
		L4	+	—	+	—

and anatomical studies (cont)

Annulus ventral part	Macrosc exam of disc deg Grade 0–3	Microsc. exam of deg Grade 0–3	Vascular buds observed Upper central	Upper lateral	Lower central	Lower lateral
++	0	0	+	—	+	+
++	0	0	+	—	+	+
+	0	0	×	—	×	—
+	0	0	×	—	×	—
not perf.	0	0	+	×	+	×
not perf	0	0	+	×	+	×

the central portion of the end plate Thus 9 specimens were impermeable whereas only 5 were expected to be so assuming an equal distribution between permeable and impermeable specimens vs degree of disc degeneration No correlation was found between degeneration and permeability of the lateral portion of the end plate but of 8 end plates with impermeability both of the lateral and central portion 6 were found to belong to discs with grade 2 or 3 degeneration From the hypothesis of equal distribution of specimens with impermeability between discs with grade 0 or 1 and discs with grade 2 or 3 degeneration only 2 5 were expected Thus a significant positive correlation exists between disc degeneration of grade 2 or 3 and impermeability of the end plate

Between disc degeneration and permeability of the annulus fibrosus no correlation was found There were only five impermeable annulus specimens This is probably due to an experimental artifact since it has been argued that even the apparently impermeable specimens of the annulus would have eventually allowed dye penetration

Permeability vs the presence of contacts between the end plate cartilage and the marrow cavity

Histologically 8 totally impermeable end plates showed an absence of contacts between the end plate cartilage and the medullary cavity of the underlying bone and these plates were markedly thicker and more dense than were end plates in which such contacts were present The histology of the lateral portion of the end plate was studied in 60

Table 2 Results of diffusion experime

Spine no	Age years	Disc	Upper central	End plate		Lower lateral
				Upper lateral	Lower central	
17	11	L3	+	—	+	+
		L4	+	—	+	+
18	5	L3	+	—	+	—
		L4	+	—	+	—
19	0	L4	+	not perf	+	not perf
		L5	+	not perf	+	not perf

× = not examined histologically

end plate cartilage and the medullary cavity of the vertebral body (Figure 3) Such communications between the medullary cavity and the articular cartilage are known to exist in synovial joints of man (Greenwald & Haynes 1969)

Permeability vs histological appearance of the end plate

The histological appearance of the end plate sections on the 0–3 scale showed no correlation with diffusion through the annulus nor through the two areas of the end plate (Table 2) In this connection it should be pointed out that in cases with high grades of end plate degeneration numerous scattered areas showed little or no degenerative changes

Permeability vs the age of the specimen

No correlation was observed between the permeability and the age of the specimen except in the central portion of the end plate where an apparent decrease in permeability with advancing age could be attributed to the appearance of significant macroscopic degeneration in the older age groups (see *Permeability vs macroscopic disc degeneration)*

Permeability vs macroscopic disc degeneration

A correlation was sought between the degree of degeneration as assessed by the naked eye appearance of the disc and the permeability of the three groups of specimens A significant positive correlation was found between discs with grades 2 and 3 degeneration and impermeability of

sels) through which the material might have leaked Thus transport through the material in life could not have occurred The impermeable specimens were examined for no longer than 48 hours and it might have been the case that had they been examined for longer some dye would have penetrated the apparently impermeable specimens Penetration after this length of time would imply such a reduced permeability that from the nutritional standpoint it seems resonable to regard the specimen as having been impermeable Our observation that the dye was sharply held up at the calcified zone implies that there was a block to permeability at this level in the end plate specimens and therefore suggests that even if the specimens had been left for a longer period of time no dye would have penetrated them On the other hand we believe for reasons advanced above (see Results) that apparently impermeable specimens of the annulus would have allowed dye penetration if given sufficient time

To summarize we therefore feel that this method can be used to determine which routes are nutritionally insignificant but that it cannot be used to provide a quantitative comparison of the relative significance of the various potentially available routes

We have found that two routes appear to be potentially available that through the centre of the end plate and that through the annulus The peripheral portion of the end plate is nearly always impermeable and would therefore seem to be of no practical functional significance as a nutritional route For reasons outlined above we are unable to say whether the annulus or the central portion of the end plate represents the more important nutritional route in life

It might be thought that the demonstration of permeability of the central portion of the end plate contradicted the earlier observations of Maroudas et al (1969) that the bone/cartilage interface was relatively impermeable and hence unimportant as a source of cartilage nutrition This apparent contradiction is resolved by our finding that the end plate was permeable only when marrow spaces in direct contact with the cartilage could be seen histologically Such a route of diffusion has been shown to exist for instance in the rabbit knee joint (Ekholm 1951) Vascular buds or marrow space contacts with the cartilage are probably absent or very few in number in the bone/cartilage interface in adult synovial joints Furthermore articular cartilage has a thicker calcified layer than has the normal or degenerative end plate (Lewin 1964 and the present study) Thus if the permeability of the central portion of the end plate depends entirely upon these marrow space con

specimens (Table 2) In all 16 cases where diffusion occurred through the lateral part of the end plate, there were marrow contacts with the cartilage in the histological sections In contrast the remaining 41 lateral end plate specimens showed no diffusion and no such contacts In the 20 specimens of the central portion of the end plate which were examined histologically contacts between marrow spaces and end plate cartilage were present All these 20 specimens were permeable

Thus specimens possessing such contacts were invariably permeable and specimens lacking these contacts were invariably impermeable

DISCUSSION

The method used on this study to examine the permeability of the end plates of the lumbar discs and of the annulus obviously does not closely simulate the physiological situation It does however have the advantage over more physiological methods that the permeability of defined areas of these tissues can be examined and that human material can be used The method departs from a physiological situation in two ways the tissue is dead and has been subjected to storage and the transport of dye through the specimen examined depends entirely upon diffusion

The effect upon permeability of death and subsequent storage has been examined by Maroudas et al (1969) who concluded that no significant change from the situation obtaining in life could be attributed to death itself to storage for a short time at +4°C nor to storage for longer periods at —20 C It would thus seem reasonable to suppose that the permeability of the tissues examined in this experiment was similar to their permeability in life

No quantitative conclusions can be drawn from this study since the thickness of the specimens in the diffusion chambers could not be accurately controlled Thus if a specimen was shown to be permeable it could be concluded that a nutritional route through the specimen in question was potentially open in life but no conclusion could be drawn as to the extent to which the nutrition of the disc might have depended upon the route in question On the other hand if a specimen of the end plate but not of the annulus was demonstrated to be impermeable it could be concluded that no physiologically significant nutrition could have occurred through that specimen Impermeability in this experimental situation implies that the tissue itself was impermeable and that it contained no pores (in life containing for example blood ves

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tacts with cartilage and if the calcified zone is impermeable our observation upon the end plates and the observation of Maroudas et al (1969) upon synovial joints are perfectly compatible We thus conclude that the nutritional route to the nucleus through the end plates depends upon these contacts or vascular buds This conclusion is similar to that reached by Greenwald & Haynes (1969) who showed that dye penetration from bone to cartilage in the human femoral head also only occurred via such vascular contacts

Our observations although compatible with the widely held view that the intervertebral disc is nourished by diffusion through its end plates, demonstrate that usually only the central portion of the end plate can function in this way since the lateral portion is generally impermeable Our observations further suggest that nutrients may reach the periphery of the disc by diffusion through the annulus fibrosus Thus it appears that the disc may depend upon two nutritional routes (a) diffusion through the central portion of the end plate from wide ampulla like contacts between the medullary cavity of the bone and overlying cartilage (the vascular buds) and (b) diffusion through the annulus fibrosus from the surrounding vessels

The central portions of a small number of end plates were found to be impermeable A statistically significant correlation was found between impermeability of the central portion of the end plate and the presence of Grade 2 or 3 degeneration as assessed by the macroscopic appearance of the disc The association between impermeability of the end plate and the presence of marked degeneration of the disc was further strengthened by the finding that all the totally impermeable end plates were found in discs showing Grades 2 or 3 degeneration as assessed by their macroscopical appearance The question arises is the association between impermeability of the end plate and degeneration of the disc one of cause and effect? Our observations would suggest that if these factors are causally connected it is not because degeneration invariably causes impermeability since many markedly degenerate discs had permeable end plates It might be argued that degeneration only results in impermeability after the passage of time and hence that in this study only a few degenerated discs had had the opportunity to develop impermeable end plates Although this possibility cannot be excluded it seems to us more likely that degeneration does not cause impermeability of the end plate since the histological appearance of the end plate in the degenerated discs particularly the finding of penetration of the end plate by vascularised connective tissue suggests that

if anything the development of degeneration in the disc may render an originally impermeable end plate permeable. Thus if there is a causal link between these two factors it seems likely to be due to the fact that impermeability of the end plate causes disc degeneration. If this is so impermeability must be only one of several causes of disc degeneration since many degenerate discs are not impermeable. It is interesting to note that Greenwald & Haynes (1969) also noted a disappearance of vascular buds and consequently a reduction in permeability with the development of degenerative changes in the human femoral head.

Thus our results suggest that whereas the normal disc is dependent nutritionally upon the annulus fibrosus and the central portion of the vertebral body end plate, certain end plates are deficient in marrow space contacts with the end plate cartilage and as a consequence are impermeable. It may be that the result of impermeability is an inadequate supply of nutrients to the disc which in turn may cause the fall in pH and increase in lactic acid concentration observed in certain degenerated discs (Diamant et al. 1968, Nachemson 1969). If this is the case the absence of marrow space contacts with the cartilage of the central portion of the end plate may be a cause of disc degeneration.

SUMMARY

Previous *in vivo* and *in vitro* experiments using dye and radioactive glucose and sulphate have demonstrated that the calcified zone of articular cartilage in normal adults is for practical purposes impermeable. Such impermeability should it occur in the intervertebral disc might be relevant to premature disc degeneration and would throw doubt on the importance of the osseous route for nutrition of the disc.

The present investigation has demonstrated that there is a statistically significant difference in permeability between the lateral portion of the end plate on the one hand and the central portion of the end plate and annulus fibrosus on the other, the latter two usually being permeable, the former impermeable.

Histological examination revealed that permeability of the end plate was always associated with the presence of "vascular buds" (vascular projections making wide ampulla-like contacts between the marrow space of the vertebral body and the hyaline cartilage of the disc's end plate). Thus this study suggests that two nutritional routes are open for the intervertebral disc: (1) diffusion through the central portion of the end plate from these marrow space cartilage contacts and (2) dif-

fusion through the annulus fibrosus from the surrounding vessels. Our observations do not allow us to comment on the relative importance of these two routes in life; all we can say is that they are both potentially available.

Of 9 impermeable central portions of 75 end plates tested, 7 were from segments with degenerated disc (Grades 2–3). Impermeability of both the central and lateral portions of 71 end plates studied was seen in 8 end plates. Of these 6 were from segments with degenerated discs.

Thus a statistically significant association was observed between impermeability of the end plate and the presence of microscopic disc degeneration of Grades 2 and 3. The pathological significance of this association is discussed, and it is suggested that the absence of marrow space contacts with the cartilage in certain end plates results in impermeability of the end plate which in turn may interfere with disc nutrition and be a cause of disc degeneration.

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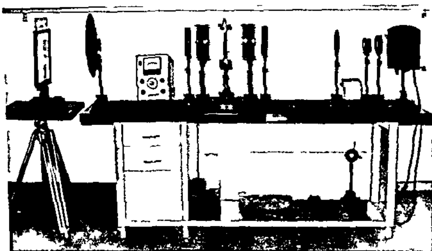


Figure 1 Pol riscope

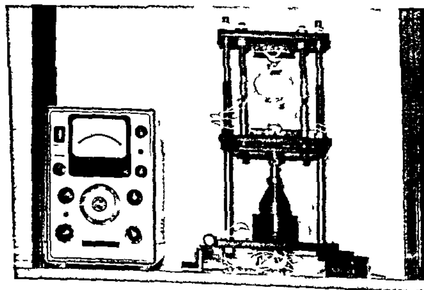


Figure 2 Model suspens on in tensomet r

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STRESS TRAJECTORIES IN THE PATELLA

Study by the Photoelastic Method

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Received 13 ii 70

During the flexion extension movements of the knee joint the patella sweeps freely up and down in a range of 5–7 cms (Fick 1911) On the final forceful extension it is subjected to a force of tension generated by the contraction of the quadriceps muscle that tightens its tendinous insertions and pulls the patella upward In full flexion the patella is also subjected to a force of tension that pulls it downward Both forces press the patella against the underlying bone so that it cannot move

Analysis of magnitude and direction of these forces are not well established and it is difficult to understand them from a mechanical point of view However stresses and strains in the patella can be quantitatively analysed as has been done with other bones (Kummer 1966 Milch 1940) by means of the photoelastic method studying models made of transparent material that becomes doubly refractive when stressed In this method the refractive axis coincides with the principal stress axis and the difference in velocity change of light transmission through these two axes is proportional to the difference in magnitude of the principal stress thus the lines of constant difference between stresses can be made visible

In order to establish the stress trajectories in the patella a 83 × 63 mm Epoxy resin model of the patella was made and subjected to a 75 kp force for experimental stress analysis in the polariscope

The following assumptions were made

(1) The patella has a uniform thickness 13.5 mm
(2) The force in the muscle is evenly distributed along the superior and inferior borders

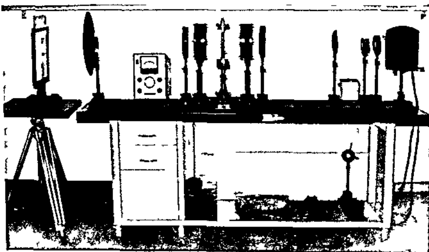


Figure 1 Polariscope

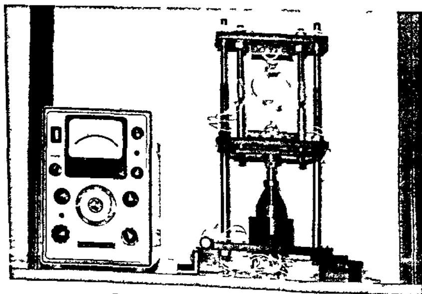


Figure 2 Model suspension n tensometer

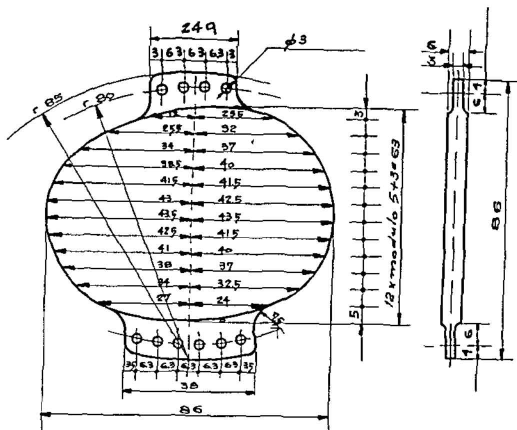


Figure 3 Model dimensions in mm

(3) The suspension shown in Figure 2 approximately resembles the actual suspension of the patella in the muscle

(4) The load is such that the single tensile force acts on the patella without any friction or perpendicular forces to the patella

METHOD

In order to find the stress distribution a lens type polariscope Riken Keiki type PHS 150 was used (Figure 1) The dimension of the polarizer was 150 mm The light source was an incandescent filament lamp of 300 W To provide monochromatic light a filter transmitting green light at 5461 Angstrom was used The model was made of Epoxy resin with material fringe value f ~ 1 mm/kg The thickness of the model material plate was 6 mm The model dimensions are given in Figure 3

To measure the force a specially made tensometer utilizing a strain guage technique was applied (Figure 2) The usual parameters of isoclinics were obtained using white light and plane polariscope arrangement Isochromatics were found by circular polariscope arrangement (with quarter wave plates) and with monochromatic

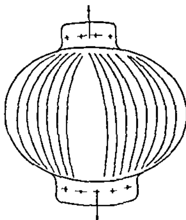


Figure 4 Isostatic lines

light. Both dark field and light field arrangements were used For some patterns the tracing technique using a screen together with a special converging lens was employed Some of the patterns were obtained using a Canon camera

Isostatic lines were established by the isoclinic pattern shown in Figure 4 The principal stresses were found by the shear difference method which implies the determination of the isostati and the isochromatic distribution in the model

To verify the experimentally found details theoretical principal stresses were calculated for a number of points in the model It was assumed that the stresses in the horizontal and vertical direction in the model consisted of two Boussinesq stresses and a hydrostatic compression equal to $\frac{2P}{d\pi t}$ (a solution similar to that developed by Michell in 1900 for a cylinder (6) The following equations were used in the calculations (Timoshento & Goldier 1951))

$$Z_x = \frac{p}{2\pi}\left[2\theta + 2\sin\theta\right]_{\theta_1}^{\theta_2} \qquad (1)$$

$$Z_y = \frac{p}{2\pi}\left[2\theta - 2\sin\theta\right]_{\theta_1}^{\theta_2} \qquad (2)$$

$$Z_{xy} = \frac{p}{2\pi}\left[\cos 2\theta\right]_{\theta_1}^{\theta_2} \qquad (3)$$

where p is the stress in kp/cm² along the line of application of the total load which amounted to 7 kp The angles θ_1 θ were measured between the vertical and horizont l orientations to the point in quest on (Figure 5) The contribution of the load on one side was added to the contribution of the load on the opposite side To make the lo d equal to O at the boundaries of the model it was assumed that

a compressive force of 12 7 kp/cm² was applied to the model The total stress in horizontal direction was

$$\sigma_x = \frac{p_1}{2\pi}\left[2\theta + \sin 2\theta\right]_{\theta_1}^{\theta} + \frac{p}{2\pi}\left[2\theta + \sin 2\theta\right]_{\theta_4}^{\theta_3} - 12\ 7 \quad (4)$$

Similarly in the vertical direction

$$\sigma_y = \frac{p_1}{2\pi}\left[2\theta - \sin 2\theta\right]_{\theta_1}^{\theta} + \frac{p}{2\pi}\left[2\theta + \sin 2\theta\right]_{\theta_3}^{\theta_4} - 12\ 7 \quad (5)$$

where $p_1 = 33\ 3$ kp/cm² and $p = 50\ 3$ kp/cm²

For the shearing stress the contributions are unaffected by hydrostatic compression and becomes

$$\tau = \frac{p_1}{2\pi}\left[\cos 2\theta\right]_{\theta_1}^{\theta} - \frac{p}{2\pi}\left[\cos 2\theta\right]_{\theta_3}^{\theta_4} \quad (6)$$

The maximum principal stress therefore is given by

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right) + \tau_{xy}} \quad (7)$$

Both the experimental and theoretical stress distribution are shown in Figure 5 The values of the stresses at points along the boundaries indicate that Eqs (4) (5) and (6) were approximately correct

Table 1 Experimental principal stresses along lines 3 and 4 in Figure 5

Line 3 (kp/cm²)	Line 4 (kp/cm²)
1 73	1 95
7 39	7 00
13 70	9 97
21 21	22 00
24 85	28 21
29 17	30 63
26 07	25 00
20 40	17 86
10 80	9 12
8 05	4 90
2 20	0

Principal stresses at 20 mm intervals begin at points A and B in Figure 5

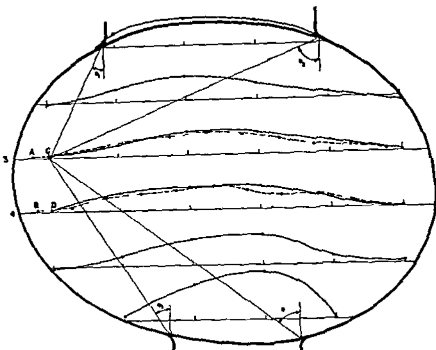


Figure 5 Experimental and theoretical distribution of principal stresses

——— Theoretical distribution
- - - - - Experimental distribution
4 9 kp/cm² in prototype
10 kp/cm² in model

RESULTS

From the isochromatic and isoclinic fringe patterns the principal stresses were deduced (Dailey & Rilley 196) An approximate theoretical formula was derived to find the theoretical distribution of the stresses for comparison As can be seen from Figure 5 which shows the principal stresses and Tables 1–2 the theoretical and experimental stresses are of the same magnitude It appears that the lower part of the model is subjected to higher stress than elsewhere The outer parts beyond the zero fringe carry very little load and from a strength point of view could be ignored However undoubtedly these parts serve other purposes such as stability of the element

The isoclinic pattern obtained (Figure 6) using 10 different angular positions of the polarizer shows a limited region of stresses inclined

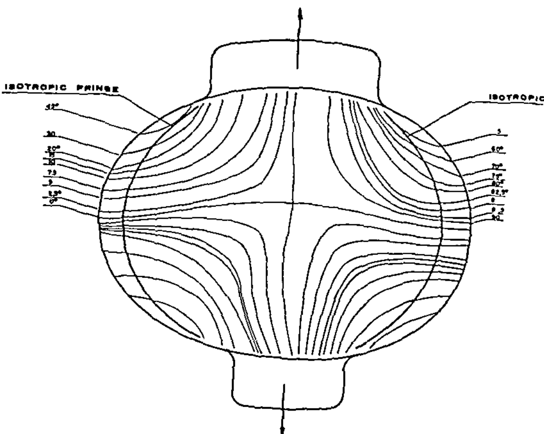


Figure 6 Isoclinics pattern

Table 2 Theoretical principal stresses along lines 3 and 4 in Figure 5

Line 3 (kp/cm²)	Line 4 (kp/cm²)
1 36	1 37
15 33	24 97
31 22	31 23
29 11	32 11
17 43	12 87
0 48	0 64

Principal stresses at 40 mm intervals begin at points C and D in Figure 5

30° or more (Figures 7 a and 7 b) Most of the force transmitted across the model is due to stresses in the vertical or almost vertical direction This should be expected owing to the geometrical form of the element and the manner in which the forces are applied



Figure 7a

Figure 7 Isoclinics patterns a at 30 b at 90

Figure 8 shows the isochromatic pattern that is the lines along which the difference between the two principal stresses is constant A concentration of fringes appears in the vicinity of the inferior border indicating a higher stress level here The fringe pattern is irregular due to the lack of symmetry in the configuration and loading

From the data it is clear that the maximum principal stresses are tensile whereas the other principal stresses sometimes are compressive particularly in the central part of the element In other words the maximum shearing stress is high here

Figure 5 shows two scales one for the model and one for the prototype The latter was obtained using an average thickness of

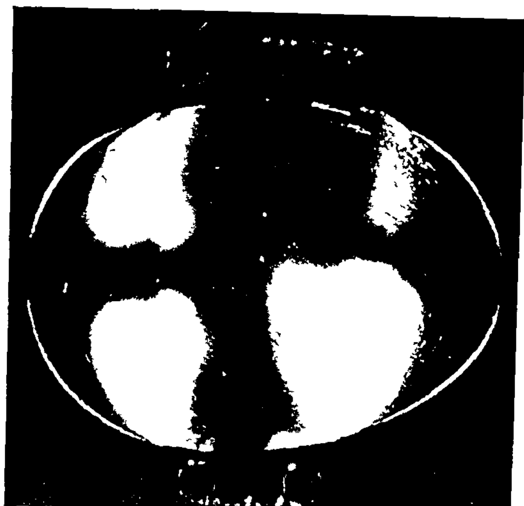


Figure 7b

13.5 mm of the prototype and a force of 42 kp in the muscle of an average male person (Steindler 1955).

DISCUSSION

During full range of active mobility of the knee joint in flexion-extension the patella is under the action of two opposite forces applied over a common axis that pull it apart: one is supplied directly by the quadriceps muscle and the other by the hamstring muscles acting via the ligamentum patellae.

The forces exerted by quadriceps acting in the knee joint during active extension have been calculated in different positions and the maximum moment has been recorded at 10–120° with reduction on

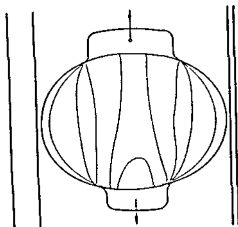


Figure 8 Isochromatic

further flexion and extension (Lindahl et al 1969) However the distribution of these forces on patella is not known Based on the experimental and theoretical analysis presented the stress trajectories of the forces applied in the patella seem to conform to the following pattern

(1) The forces applied in patella are transmitted vertically
(2) The lower part of the patella is subjected to higher stresses than elsewhere Transverse fracture caused by violent contraction of the quadriceps while the knee is being forcibly bent by the weight of the body is most commonly situated in the lower half as the triangular shaped patella
(3) The principal stresses are tensile but in the central part they are compressive the maximum shearing stress is higher here In chondromalacia patellae the degenerative changes in the articular cartilage may thus be the result of a compressive stress

SUMMARY

Using the photoelastic method experimental and theoretical stress analyses were calculated in the patella using a model of this bone made of Epoxy resin subjected to a force of 75 kp Most of the forces applied to the model were transmitted vertically with higher stress level in the inferior border The principal stresses are tensile but in the central

part they are compressive This can explain some details of the transverse fracture of the patella by indirect violences as well as chondromalacia of this bone

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Orthopaedic Hospital Copenhagen Denmark

ON THE INFLUENCE OF INTERTROCHANTERIC OSTEOTOMIES UPON THE GROWTH AND VASCULARIZATION OF THE PROXIMAL PART OF THE FEMUR IN YOUNG RABBITS

H Bohr Chr Hansen Leth & I Reimann

Received 23 ii 70

It is well known that stimulation of growth in long bones takes place following different interventions on the bones This is especially the case after an osteotomy or a fracture and references to the extensive literature are lately given in surveys by Sundén (1967) and Hedström (1969) The question of the causal relationship has been thoroughly discussed by these authors and there seems to be general agreement as to the decisive influence of the vascular supply

In the present investigation the growth rate at the proximal part of the femur in young rabbits has been measured by tetracycline labeling following partial or total osteotomies as an indicator of the vascular supply At the same time direct visualization of the vessels has been attempted by microangiographic studies

EXPERIMENTS

White female rabbits 3 months old and weighing about 1 5 kg were used for the experiment They were kept in separate cages and fed on vegetables and given extra supplies of minerals and vitamins Operations were performed with Nembutal anesthesia (40 mg per kg) under sterile conditions exposing the left femur at the trochanter region In 10 animals a partial intertrochanteric osteotomy was made with a hand driven circular saw blade and the bone marrow eroded with a pointed knife resulting in a profuse bleeding of only short duration however As a fracture of the femur arose unintentionally in 5 of these animals either during the operation or immediately after the osteotomy was somewhat restricted in the rest of the animals In another

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Through perfusion with saline under 1 m water pressure the remaining blood was washed out of the vascular system in the lower half of the body The perfusion was continued with saline containing 2 per cent Berline blue followed by 25 per cent Micropaque with 2 per cent Berline blue and concluded with a mixture of 25 per cent Micropaque with 10 per cent formalin The lower half of the body was skinned and kept in 10 per cent formalin for several days

The operation side in each animal was dissected and in the case of microangiography the skeleton of the lower half of the body was cleaned of soft tissue except periosteum and ligaments as shown in Figure 1 in order to preserve the vessels to the bones The proximal part of the right and left femur including the head of the femur and the great trochanter was removed from all animals In the first series the whole specimen was embedded in methyl metacrylate while in the second series the specimen was first divided in equal halves one of which was decalcified before embedding and the other half embedded directly in methyl metacrylate With a rotating saw each specimen was cut in the frontal plane perpendicular to the epiphyseal plate and through wet grinding sections about 50 μ thick were obtained from the undecalcified specimen while sections 2 5 mm thick were prepared from the decalcified bone specimen The growth at the epiphyseal plate of the femoral head and the great trochanter was determined by the distance between the fluorescent lines corresponding to the primary calcification front at the time of tetracycline labeling Measurements were performed by fluorescent microscopy of the undecalcified specimen with a graduated eyepiece and on photographs (Tapp 1966 Hansson 1967 Bohr 1968) Microangiographic pictures of the decalcified sections were obtained using soft X rays from a Machlett A E G X ray tube with a Wolfram anode generated at 25 kV and 15 mA at a distance of 40 cm Exposures were made on Kodaline X ray films

RESULTS

Several sections from each specimen were available for the determination of growth and examples of fluorescent photographs from a case in the second series are shown in Figures 2 and 3 Between different sections from the same animal the measurements varied by about 20 per cent The effect of the operation on the growth was determined as the difference between the growth rate on the operated left and the



Figure 1. Dissection of animal No. 348 sacrificed 10 days following total osteotomy and internal fixation. Magnification × 1.

series including 12 animals a total osteotomy was performed in the same region using a Gigli saw and followed by application of a small plate with 2 or 3 screws for internal fixation (Figure 1). All the animals recovered from the operation and no inflammation occurred. Between 6–33 days after the operation tetracycline labeling on the bones was performed through i.m. injections of Reverin (Pyrolidino methyl tetracycline 30 mg per kg). In the first series these injections were repeated twice with intervals of 6 days and in the last series with intervals of only 3 days. The animals were sacrificed one day after the second injection and in the last series microangiography was performed according to a modification of the method of Trueta & Harrison (1953) as follows. During Nembutal anesthesia the peritoneum was opened and a cannula placed in the aorta after which the animals which had previously been heparinized were bled from the veins

Through perfusion with saline under 1 m water pressure the remaining blood was washed out of the vascular system in the lower half of the body The perfusion was continued with saline containing 2 per cent Berline blue followed by 25 per cent Micropaque with 2 per cent Berline blue and concluded with a mixture of 25 per cent Micropaque with 10 per cent formalin The lower half of the body was skinned and kept in 10 per cent formalin for several days

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Figure 2 Fluorescent photograph of a 70 μ thick undecalcified section from the operated side of animal No 056 sacrificed 10 days following total osteotomy and internal fixation The lines from tetracycline labeling given 1 and 4 days before sacrifice are seen at the metaphyseal side of the epiphyseal plate
Magnification × 25

control right side expressed in per cent of the growth rate at the control side The growth rate at the femoral head and the trochanter at different days after the operation is given in Table 1 It is seen that growth on the control side may vary more than 100 per cent from one animal to another but this individual variation is not considered influential in the difference in growth between the right and left leg in the same animal There was in general good agreement between the results obtained at the epiphyseal plate of the femoral head and the great trochanter A summary of the results is shown in Figure 4 demonstrating that partial osteotomy did not have any significant influence on the growth whereas the fracture did stimulate the growth significantly This effect was further increased in the cases of total osteotomy with internal fixation The mean values for growth stimulation at the epiphyseal plate of the femoral head for partial osteotomy was −14 per cent for the fractures + 90 per cent and for total osteotomy + 170 per cent with a standard deviation of ± 10 per

cent For growth stimulation at the epiphyseal plate of the great trochanter the corresponding mean values were –14 + 50 and + 105 per cent respectively ± 10 per cent At the control side the average growth at the trochanter was about twice that of the femoral head The average increase in growth after total osteotomy was almost equal at both places showing that the stimulative effect on growth was of the same order

Microangiographic studies in the cases of total osteotomy showed that hyperemia was present in the proximal part of the femur on the operated side This is demonstrated in Figure 5 and 6 showing sections of both femora from animals sacrificed 19 and 32 days after the operation It is seen that the increased vascular supply on the operated side is derived mainly from periosteal vessels whereas the central vessels in the bone marrow are less developed than on the control side in accordance with the results of Guida et al (1969) The accumulation of vessels at the metaphyseal side of the epiphyseal plate is most distinct and the vascular supply to the epiphysis is increased to a lesser degree In some cases vessels seem to penetrate the epiphyseal



Figure 3 Fluorescent photograph of a 50 μ thick undecalcified section from the control side of the same animal as in Figure 2



Figure 2 Fluorescent photograph of a 70 µ thick undecalcified section from the operated side of animal No 056 sacrificed 10 days following total osteotomy and internal fixation The lines from tetracycline labeling given 1 and 4 days before sacrifice are seen at the metaphyseal side of the epiphyseal plate
Magnification X 25

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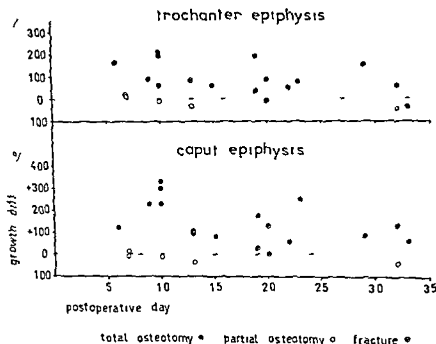


Figure 4 Growth stimulation following total osteotomy partial osteotomy and fractures

epiphysis whereas the processes of primary calcification and en chondral ossification are dependent on the blood supply to the metaphysis Stimulation of growth thus seems to presuppose an in creased vascular supply primarily to the epiphysis It has been shown by Jabsley et al (1965) that periosteal stripping and destruction of the nutrient artery in the proximal part of the femur in rabbits had only little influence on the vascularization of the epiphysis in the head of the femur This corresponds to the comparative small growth stimulus observed and according to these authors the vascular reac tion in the epiphysis was secondary to necrosis in the central part of the growth plate In the present investigation such necrotic changes were not observed and it is assumed that the stimulation of growth following total osteotomy and fractures was due to a more extensive hyperemia The failure of growth following partial osteotomy indicates that the vascular supply to the epiphysis is not increased through such an intervention As growth stimulation was greater in cases of total

Table 1 Growth at the epiphyseal plate (ep pl) of the femoral head and the great trochanter following intertrochanteric osteotomy and fracture according to the postoperative day of sacrifice of the animal

Animal no	Operation	Day postop	Ep pl femoral head growth (μ/day)			Ep pl trochanter growth (μ/day)		
			Right	Left	Diff %	Right	Left	Diff %
289	total osteot. + int fix	6	20	45	+120	30	80	+1[illegible]0
70 E	– –	9	35	115	+230	60	115	+ 90
056	– –	10	35	115	+230	75	120	+ 60
348	– –	10	35	150	+330	75	220	+190
787	– –	10	20	80	+300	45	135	+200
750	– –	15	70	125	+ 80	65	105	+ 60
40 E	– –	19	20	55	+175	45	130	+190
022	– –	22	40	65	+ 60	70	105	+ 50
745	– –	23	40	140	+250	110	190	+ [illegible]5
366	– –	29	30	55	+ 85	30	75	+150
61 E	– –	32	60	140	+135	100	160	+ 60
328	– –	33	30	50	+ 65	40	25	— 35
75 E	part osteot. + fracture	13	20	40	+100	25	45	+ 80
88 E	– –	13	30	60	+100	50	?	?
10	– –	19	40	50	+ 25	80	110	+ 35
11	– –	20	40	90	+130	80	145	+ 80
311	– –	20	35	35	0	40	45	+ 10
79 E	part osteot — fracture	7	100	90	— 10	110	120	+ 10
N (0)	– –	7	55	65	+ 20	90	100	+ 10
451	– –	10	85	80	— 5	110	100	— 10
506	– –	13	80	50	— 35	80	50	— 35
335	– –	32	85	50	— 40	110	60	— 45

plate from the metaphysis to the epiphysis of the head of the femur and enlarged vessels from the periphery encircle the epiphysis of the trochanter

DISCUSSION AND CONCLUSION

In the work of Trueta et al (1960 a b c) the growth reaction to disturbances of the vascular supply to the epiphyseal and metaphyseal side of the growth plate has been studied It appears that the proliferation of cartilage cells is mainly dependent on the blood supply to the

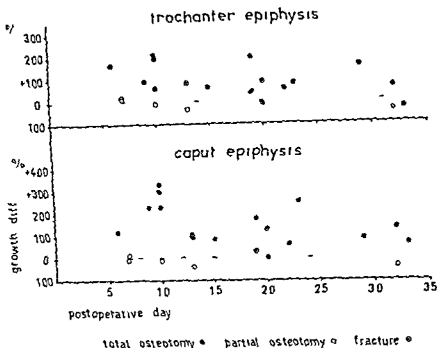


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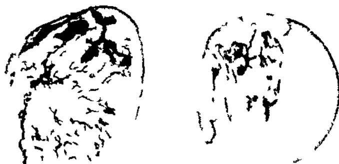


Figure 5. Microangiographic exposure of a 2.5 mm thick decalcified section from the proximal part of animal No. 40 F sacrificed 19 days following total osteotomy and internal fixation. Operated side to the left, control side to the right. Magnification × 1.

osteotomy with internal fixation than in cases of fractures, it indicates that internal fixation with plate and screws promotes hyperemia. This effect may also be applied to less extensive interventions such as partial osteotomy.

In this connection the beneficial influence on coxarthrosis obtained by subtrochanteric osteotomy without interfering with weight bearing forces (Nissen 1963) should be considered. It may be assumed that an increase in the vascular supply to the hip will improve the nutritional state of the cartilage and promote restitutional processes, but further investigations are needed in order to elucidate these problems.

SUMMARY

In three month old rabbits the growth rate at the epiphyseal plates of the femoral head and the great trochanter has been studied through



Figure 6. Microangiographic exposure [illegible] mm thick decalcified section from the proximal part of animal No. 61 E sacrificed 3[illegible] days following total osteotomy and internal fixation. Operated side to the left, control side to the right. Magnification × 1.

tetracycline labeling during 1–4 weeks following osteotomies at the proximal part of the femur It was shown that partial intertrochanteric osteotomies did not have any significant influence on the growth but when fractures occurred during such an intervention the growth rate at the epiphyseal plate of the femoral head was increased by 70 per cent and at the epiphyseal plate of the trochanter by 38 per cent In 12 rabbits where a total intertrochanteric osteotomy was performed and followed by internal fixation the average increase in growth rate was 170 per cent and 105 per cent respectively Through microangiographic studies in these animals an increased blood supply to the metaphysis and epiphysis was also demonstrated It is concluded that the increased growth was due to hyperemia also comprising the epiphyseal bone

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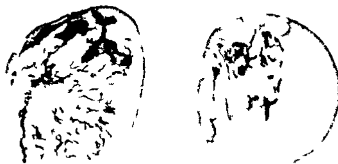


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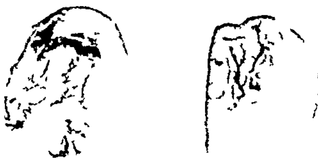


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RESULTS

The serum calcium test taken at the time of admission could not be demonstrated to contribute to the diagnostic procedure in one single case out of the 401 The distributions of age serum calcium and serum protein in men and women are demonstrated in Table 1

Table 1 Age serum calcium and serum protein in 213 male and 189 female orthopaedic patients

	Men Av ± SD	Women Av ± SD
Age	48 1 ± 20 25	52 9 ± 20 64
Serum calcium meqv/lit	4 93 ± 0 30	4 89 ± 0 29
Serum protein g %	7 27 ± 0 64	7 21 ± 0 61

Table 2 Linear correlation coefficients of the relationships between age serum calcium and serum protein

	Men	Women
Serum protein vs serum calcium	0 531	0 401
Age vs serum calcium	—0.323	—0 198

There was a significant negative correlation between age and serum calcium in men as well as in women the correlation was stronger in the men (Table 2) There was also a significant positive correlation between serum protein and serum-calcium For any given serum protein level the serum calcium level did not differ between men and women (analysis of covariance) There was no significant difference between fracture cases as compared to other cases admitted to the department with respect to the serum calcium level

DISCUSSION

Patients admitted to an orthopaedic department may in fact not deviate very much with respect to their calcium metabolism from the general population to which they belong except that there is an excess of elderly individuals who have sustained fractures and in whom bone fragility related to osteoporosis is one of the causing factors

The fact that no difference in serum calcium levels could be

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SERUM CALCIUM IN ORTHOPAEDIC PATIENTS

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Received 4 iv 70

Bostrom & Wengle (1969) demonstrated the value of serum calcium as a screening test in internal medicine In 509 female patients they found 3 cases of hypocalcemia and 4 cases of hypercalcemia to whom the result of the screening test had been of importance for the final diagnosis and treatment Keating et al (1969) found that in healthy adults the serum calcium decreased with age in men but not in women Conversely Roberts (1967) found such an age relationship in women but not in men

The object of the present study was to investigate the value of serum calcium as a screening test in orthopaedics and to study the age and sex relationships of serum calcium in orthopaedic patients

MATERIAL AND METHODS

Half of the cases in the Department of Orthopaedic Surgery General Hospital Malmö are admitted for reconstructive surgery whereas the remainder are admitted because of trauma Very few have long standing severe disability such as chronic tuberculosis of the spine polio or paraplegia During the time of the study rheumatoid arthritis only occupied a small part of the hospital beds

Serum calcium and serum protein were among the laboratory investigations routinely performed at the time of admission during the years 1965–1969 These values were determined by the flame photometry method and the method for estimation of total protein according to Biuret respectively The precision of both methods was less than 3 per cent (coefficient of variation)

Four hundred and one patients 213 men and 189 women were randomly selected from the record room The only patients excluded from the study were those with cancer metastases to the skeleton Only a few of the individuals in the sample had been unable to walk prior to admission or prior to the accident causing admission The records were studied for the final diagnosis of the patient and its possible relationship to the serum calcium value obtained at the time of admission Age serum protein and serum calcium were correlated and compared between men and women

Probability levels better than 99 per cent have been referred to as significant

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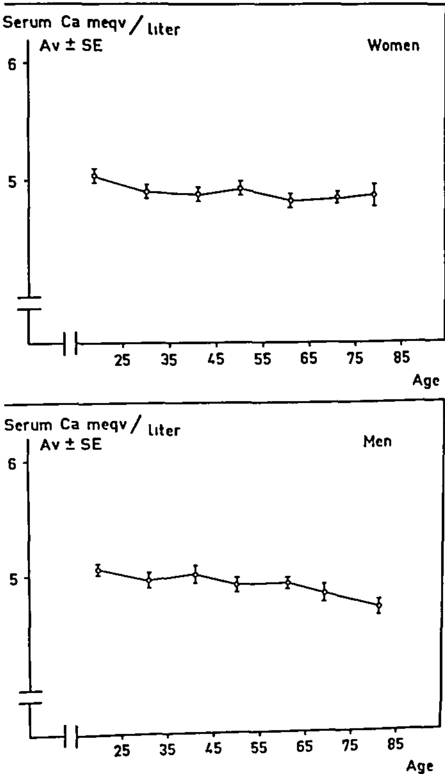


Figure 1 Serum calcium (average ± SE) at average age within 10 year groups

demonstrated between fracture cases and other cases does not exclude differences between these groups as the blood samples were drawn at the time of admission when the fracture healing process had not yet started

The difference in the age relationships of serum calcium in men as compared to women may be studied more closely by dividing the patients into age groups (Figure 1) Within the sexes there was no significant difference between any subsequent 10 year groups as demonstrated by the standard errors in Figure 1 There was a tendency of decreasing serum calcium throughout the age groups in both sexes However there was an obvious deviation from this pattern in women in that the decreasing tendency ceased or was even reversed after the age of 55 This finding indicates a slight increase in serum calcium after the age of 55 in women as compared to men or at least the presence among the women who are orthopaedic patients of a subset with an increasing serum calcium level The increase may be related to the process of bone resorption and osteoporosis after menopause

SUMMARY AND CONCLUSION

In 401 orthopaedic patients it could not be demonstrated that a serum calcium test at the time of admission to hospital contributed to the diagnostic procedure In the same patients it was found that the serum calcium level decreased with age more so in men than in women and that the women deviated from the men after the age of 55 when the serum calcium level remained constant or possibly somewhat increased

ACKNOWLEDGEMENT

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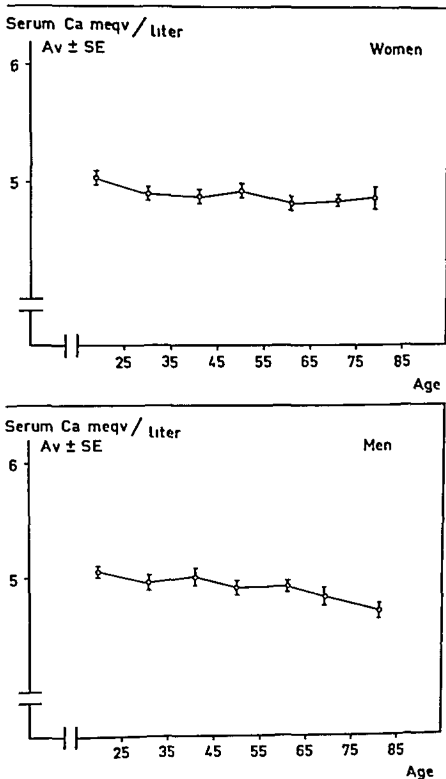


Figure 1 Serum calcium (average ± SE) at average age within 10 year groups

demonstrated between fracture cases and other cases does not exclude differences between these groups as the blood samples were drawn at the time of admission when the fracture healing process had not yet started

The difference in the age relationships of serum calcium in men as compared to women may be studied more closely by dividing the patients into age groups (Figure 1) Within the sexes there was no significant difference between any subsequent 10 year groups as demonstrated by the standard errors in Figure 1 There was a tendency of decreasing serum calcium throughout the age groups in both sexes However there was an obvious deviation from this pattern in women in that the decreasing tendency ceased or was even reversed after the age of 55 This finding indicates a slight increase in serum calcium after the age of 55 in women as compared to men or at least the presence among the women who are orthopaedic patients of a subset with an increasing serum calcium level The increase may be related to the process of bone resorption and osteoporosis after menopause

SUMMARY AND CONCLUSION

In 401 orthopaedic patients it could not be demonstrated that a serum calcium test at the time of admission to hospital contributed to the diagnostic procedure In the same patients it was found that the serum calcium level decreased with age more so in men than in women and that the women deviated from the men after the age of 55 when the serum calcium level remained constant or possibly somewhat increased

ACKNOWLEDGEMENT

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THE QUADRATE LIGAMENT OF THE ELBOW—ITS RELATIONSHIP TO THE STABILITY OF THE PROXIMAL RADIO ULNAR JOINT

MORTON SPINNER & EMANUEL B KAPLAN

Received viii 69

INTRODUCTION

It has been demonstrated clinically that the proximal radio ulnar joint is most stable in supination The purpose of this paper is to present the basic anatomy responsible for this observation Fifty elbows both fresh and preserved specimens were studied The findings were correlated with 25 clinical cases of dislocations of the radial head and Monteggia fracture dislocations of the proximal radio ulnar joint

The proximal radio ulnar joint is most stable in supination for the following reasons (1) The adult radial head is not circular but somewhat oval (Figure 1) With the forearm in supination the greatest diameter of the head comes in contact with the proximal radio ulnar joint (2) The height of the margin of the radial head is not of the same width around the head (Figures 2 and 8D) In full supination the broadest portion of *the margin of the radial head comes in contact with the* proximal radial notch of the ulna and gives the broadest articular contact (3) In full supination the interosseous membrane is most taut (4) The orbicular ligament is reinforced by the anterior and posterior components of the radial collateral ligament (5) In full supination the anterior thicker fibers of the quadrate ligament of Denucé stabilize the radial head more strongly into the proximal radio-ulnar joint

The quadrate ligament (Figure 3) was first described in 1854 by Denuce and now bears his name Little attention was given to this structure until 1955 when it was accepted as a functional structure by the Nomina Anatomica Parisiensia (N A P) Its function in the past was

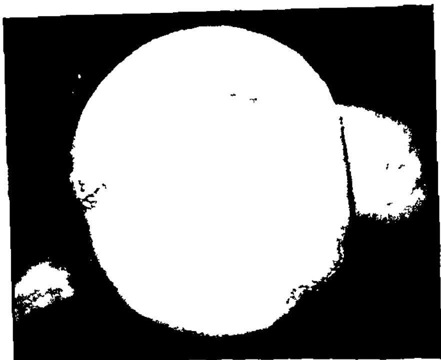


Figure 1 This adult radial head measured 1 inch in its long axis while the short axis was 7/8 of an inch

described by anatomists as a reinforcement of the inferior aspect of the capsule of the elbow joint On the basis of our studies the role of the ligament of Denucé is an important structure concerned with the stability of the proximal radio-ulnar joint These studies have shown its chief role is as an accessory stabilizer of the proximal radio-ulnar joint in full supination and pronation on account of the position of its anterior and posterior fibers in the extremes of rotation

The ligament extends between the lateral side of the proximal ulnar just distal to the proximal radio ulnar joint and attaches to the neck of the radius just distal to the articular margin The radial attachment is in line with the bicipital tuberosity The ligament of Denuce has an anterior and posterior border The anterior border is denser and stronger than the posterior border while the central portion of the ligament between the two is thin

Figure 2 The margin of the radial head is not of the same height around the head

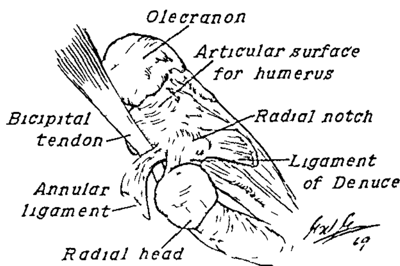


Figure 3 A line drawing of the left elbow joint with particular detail to the ligament of Denucé at the proximal radio ulnar articulation

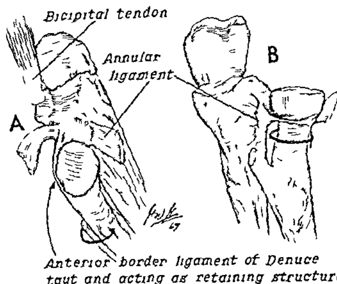


Figure 4 (A) Note when the orbicular ligament is divided the radial head can dislocate posteriorly (B) When the forearm is supinated it is the anterior border of the quadrate ligament which becomes taut and draws the radial head snugly against the radial notch of the ulna

Normal Functional Anatomy of the Ligament of Denucé

In full supination of the forearm the anterior border becomes taut around the neck of the radius drawing it snugly against the proximal radio-ulnar notch (Figure 4B) The posterior border slackens whereas in full pronation the posterior fibers become taut drawing the radial head into the sigmoid notch of the ulna while the anterior fibers become slack

MATERIAL AND METHODS

F ftv ell ows were dissected and set in 2 main groups The exten or musculature and supinator were separated from their origin and were reflected distally to ex pose the joint capsule orbicular ligament interosseous membran and the proximal one half of the radius and ulna.

Crou 1 The principal stabili er of the proximal radio ulnar joint is the orbicular ligament Dislocation of the radial head did not occur in this first group when the ulna and the o bicul r ligaments were intact and Denucé s ligament divided.

However with the ulna intact our anatom cal studies indicated that when the o bicular ligament reinforced by the anterior and posterior components of the r dial collateral ligaments were severed the radial head dislocated posterior radial

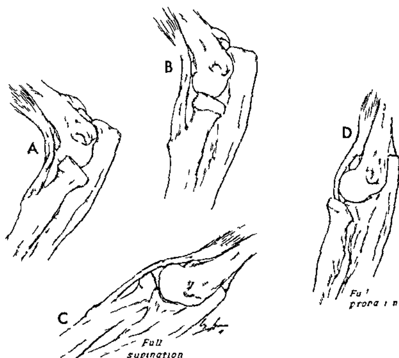


Figure 5 Left elbow A posterior dislocation of the radial head is best reduced maintained in extension and full supination (A B and C) It can also be reduce full pronation in extension (D)

or postero radial in 90 per cent of the specimens (Figure 4A) Anterior disloca was not demonstrated in any of these specimens In a few there was complete bility at the proximal radio ulnar joint with the orbicular ligament divided an these specimens the ligament of Denucé appeared short and square in outline

Division of the posterior border of the quadrate ligament in this small grou 10 per cent produced posterior or posterio radial dislocations of the radial head

All dislocations in this group could be reduced by full extension of the el (thus unlocking the radial head from the capitellum) and rotation of the fore into full supination or full pronation when the ligament of Denucé was in (Figure 5) When the posterior fibers of the ligament were severed reduction co be accomplished only in full supination If the anterior border was severed red tion occurred only in full pronation

To produce an anterior dislocation of the radial head with an intact ulna th conditions had to be met (1) the orbicular ligament had to be severed (2) posterior border of *Denucé s ligament had to be divided and (3) the oblique co* of Weibrecht and the proximal ⅓ of the interosseous membrane had to be divid (Figure 6A) With an intact ulna anterior dislocation of the radial head could r be produced unless the above structures were severed

We repeated several of Evans excellent hyperpronation experiments. In the sp cimens in which there was an anterior dislocation of the radial head without fracture of the ulna the orbicular ligament was found to be ruptured along with

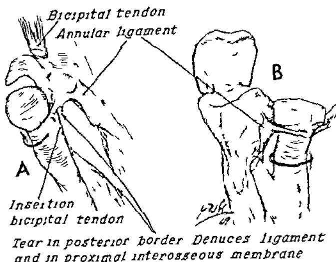


Figure 6 (A) Left elbow To produce an anterior dislocation of the radial head the orbicular ligament the posterior border of the Denucé ligament and the proximal $\frac{1}{3}$ to $\frac{1}{2}$ of the interosseous membrane (including Weitbrecht's oblique cord) must be severed (B) Reduction of an anterior dislocation occurs in full supination and is accomplished through the intact anterior border of the quadrate ligament

rupture of the posterior border of Denuce's ligament and the proximal $\frac{1}{3}$ to $\frac{1}{2}$ of the interosseous membrane (Figure 7)

The anterior dislocation of the radial head created either by dividing the three essential structures or produced by hyperpronation were reduced by fully supinating the elbows flexed at 90 degrees In these cases apparently the intact anterior fibers of Denuce's ligament reduced and stabilized the joint (Figure 6B)

Group II Twenty elbow specimens were used to study Monteggia fractures under varying conditions

Group A In five specimens the orbicular ligament was severed leaving the ligament of Denucé intact and the ulna osteotomized at the junction of the proximal and middle third By forceful angulation an anterior or posterior dislocation was produced

Group B In this group of five specimens the ulna was osteotomized high at the level of or just proximal to the radial tuberosity the orbicular ligament Denucé's ligament and the interosseous membrane were left intact (Figure 8A) With the forearm in supination and by angulating the osteotomy site posterioradially the radial head dislocated posteriorly leaving the intact orbicular ligament as an obstacle to reduction (Figure 8B) The radial head pulled out from the inferior aspect of the orbicular ligament without rupturing it. In addition the quadrate ligament is intact (Figure 8C) By pronating the forearm the posterior irreducible dislocation was converted to an irreducible anterior dislocation with the ulna abnormally rotated to 90 degrees at the osteotomy site (Figure 8D)

Group C The ulna was osteotomized at different levels in five specimens with

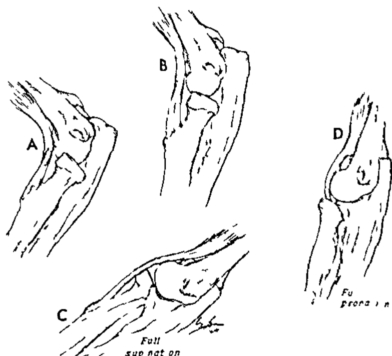


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Figure 84 Right elbow The orbicular ligament is intact

t my failed to pr duce a dislocation of the radial head in either direction unless the proximal portion of the interosseous membrane was incised Pronounced poste rior angulation at the osteotomy site produced marked widening of the proximal interos e us space resulting in a posterior dislocation of the radial head even though the integ ty of the orbicular ligament and Denucé s ligament was maintained (Figure 10) There is some doubt in the author s mind that th s type occurs clini lly

Anterior l slocations could not be produced with the orbicular ligament intact

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Figure 7 Right elbow A hyperpronation experiment (Evans type) the proximal forearm viewed from posterior reveals an anterior dislocation of the radial head with a rupture of the articular ligament (OL) the posterior border of the quadrate ligament (arrow) and the interosseous membrane (IM)

the orbicular ligament and the quadrate ligament intact in all When the ulna was osteotomized proximal to the origin of the interosseous membrane only posterior dislocation of the head of the radius by posterior angulation of the ulna was noted (Figure 9)

With the osteotomy made in the middle third of the ulna angulation of the osteo



Figure 8A Right elbow The orbicular ligament is intact

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Anterior di loc tions could not be produced with the orbicular l gament intact

Group D In this group of five specimens the orb cular ligament was incised and the ulna was osteotomized at varying levels from the level of the ulna notch to the mid shaft with the interosseous membrane intact. Dislocations of the radial head



Figure 8B A posterior Monteggia fracture dislocation has been produced with an intact orbicular ligament which is an obstacle to reduction

were constantly produced with angulation of the ulna With anterior angulation of the ulna anterior dislocation of the radial head was noted while with posterior ulna angulation posterior dislocation of the radial head was produced

CLINICAL MATERIAL

Twenty five clinical cases of dislocations of the radial head and Monteggia fracture dislocations were reviewed with particular attention to the method of obtaining and maintaining the reduction

All of the Monteggia lesions in children were reduced by closed methods in either flexion (Figures 11 A and B) or in extension depending on the type fracture dislocation All of the radial head dislocations were reduced and were maintained in full supination

The majority of adults required open reduction to stabilize the ulna The radial head component was reduced in full supination once the ulna was fixed *There was one exception*



Figure 8C The irreducible dislocation occurred when the radial head dislocated through the inferior aspect of the arbicular ligament Note that the Denuce ligament is intact

A 56 year old male was admitted to the Jacobi Municipal Hospital New York with a Monteggia lesion of the right arm on September 17 1968 Closed reduction was unsuccessful An open reduction was performed and a Leinbach screw was used to fix the ulna fracture one week later A small fragment of the radial head was found loose in the joint and was removed In supination the radial head was noted still to be dislocated posteriorly Full pronation yielded the reduction of the radial head

The probable explanation for this exception was that the anterior border of the ligament of Denuce was detached with the small fragment of the radial head leaving just the posterior border intact The radial head was reduced utilizing the posterior border of the ligament in full pronation This was confirmed at surgery subsequently when after union of the ulna was obtained and the arm mobilized in order to gain maximum rotation of the forearm the radial head was removed



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Figure 9 Group C Right arm A posterior Monteggia lesion can be produced with an intact orbicular ligament when the ulna is osteotomized proximal to the interosseous membrane

ment of Monteggia fractures Naylor (1942) initially utilized traction with pronation to gain reduction but found it impossible to maintain it He too found it necessary to place the forearm in full supination to maintain the reduction

Schubert (1965) described a case of dislocation of the radial head in one newborn The dislocation was posterio-radial In was reduced well in full supination with the arm held in extension and immobilized in this position for 2½ weeks The infant had an uneventful recovery He noted the bilateral case of Cockshott & Omolulu (1958) of a six day old female baby with bilateral dislocation of the radial head which seemed to reduce in full supination and dislocated in pronation

Furthermore it is well known that the so-called pulled elbows in



Figure 8D The same specimen can be converted into an irreducible anterior Monteggia by pronation of the forearm The orbicular ligament and capsule are still interposed between the radial head and capitellum

It revealed the fragment of radial head was from the region where the anterior border of the ligament attached

DISCUSSION

Our anatomical studies continue directly from the initial experiments of Evans (1949) in which he related anterior Monteggia fractures to hyperpronation of the forearm Evans emphasized the importance of supination in reduction of these fracture dislocations The importance of supination is further supported by the additional laboratory experiments with the functional studies of Denucé's ligament noted in this report It is the intact anterior border of this ligament with the forearm in full supination that draws the radial snugly into the proximal radio ulnar joint Earlier reports of Henderson (1931) and Wilson (1933) indicated the importance of supination postoperatively in treat

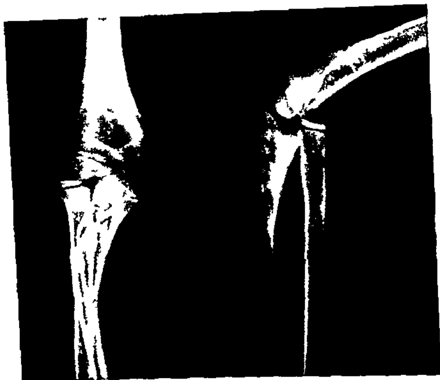


Figure 11 A

dislocations due to muscular imbalance in prolonged immobilization in an extremely abnormal position some of the radial head disloca tions in Erb s palsy may be due to an unrecognized accidental disloca tion in the newborn We are currently attempting to substantiate this viewpoint by examination of the newborn with observation and roent genograms of the upper extremities which do not respond to the Moro reflex

SUMMARY

The quadrate ligament of the elbow the significance of which is still debated is an important stabilizer of the proximal radio ulnar joint Its anterior and posterior reinforced borders play an important role in the reduction of dislocations of the radial head in Monteggia lesions dislocations of the radial head and "pulled elbows

A Monteggia lesion with a posterior dislocation of the radial head can



Figure 10 Group C Right arm Similarly posterior Monteggia fracture dislocation with an intact orbicular and Denucé ligaments but with the ulna osteotomized in its middle third To produce it the entire proximal interosseous membrane had to be divided

young children reduce in 90 degrees of flexion and full supination It is believed therefore that it is the ligament of Denucé which on the extremes of supination draws the radial head through its thickened anterior border into the proximal radio ulnar joint by wrapping around the neck and holding it firmly to this joint

In addition one may question whether some congenital dislocations of the radial head of childhood are not the end result of an accidental dislocation of the newborn which was not recognized In support of this speculation a 30 per cent incidence of dislocations of the radial head (anterior and posterior) in cases of Erb's palsy is reported by Aitken (1952) It is possible that in addition to the current concept of these



Figure 11 A

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A Monteggia lesion with a posterior dislocation of the radial head can



Figure 11 B

Figures 11 A and B Anteroposterior and lateral roentgenograms of an antero radical type Monteggia lesion reduced in flexion and full supination

occur with intact orbicular and Denucé s ligaments However a Monteggia lesion with an anterior dislocation of the radial head will have a disruption of the orbicular ligament and usually has a disruption of the posterior border of the quadrate ligament

An irreducible type Monteggia lesion can occur with intact orbicular and Denucé s ligaments The radial head dislocates inferiorly interposing the intact capsule and orbicular ligament between the radial head and capitellum

Traumatic anterior dislocations of the radial head without fracture of the ulna are associated with disruption of the orbicular ligament posterior border of the ligament of Denuce and the proximal interosseous membrane Posterior dislocations of the radial head alone occur usually just with rupture of the orbicular ligament

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VASCULARIZATION OF THE FEMORAL HEAD FOLLOWING FRACTURE OF THE NECK OF THE FEMUR

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In the course of time the common occurrence of necrosis of the femoral head after fracture of the femoral neck has been the subject of numerous publications, and it still remains a problem in the treatment of these fractures.

By now it seems to be agreed that the incidence of necrosis is about 25–40 per cent, but opinions are divided as to what influence this *should have on the primary treatment of femoral neck fractures* after the introduction of the various replacement arthroplastics, predominantly with Moore prostheses. In many hospitals these operations have become standard procedures in dealing with old patients who have sustained sub-capital fractures. By this means it is believed that the patient may avoid a possible secondary operation and can relatively soon be mobilized. Thus, prosthetic arthroplasty is bound to be performed on many patients who do not need it.

It would be a great help in the primary treatment if it were possible to point out beforehand patients likely to develop necrosis and/or non-union of the femoral head. Indeed, numerous attempts have been made, especially on the basis of studies on the vascularization of the capital fragment. Avascular necrosis is a common term, signifying that vascular injury is considered the essential pathogenetic factor in this necrosis. The blood supply to the head and neck of the femur and changes therein following fracture have been elucidated by numerous studies, *inter alios* by Brodetti (1960), Claffey (1960), De Haas & McNab (1956), *Judget et al. (1955), Sevitt (1961), Sevitt & Thompson (1965)* and Trueta & Harrison (1953). The blood supply is effected partly by vessels passing up through the neck and partly, to a varying extent, by vessels in the ligamentum teres, but especially by vessels passing beneath the synovial membrane along the femoral neck from the medial circumflex femoral artery in an inferior medial and a superior lateral

group The lateral group supplies the greater part of the femoral head including its upper weight bearing segment In transcervical fractures the vessels within the neck are interrupted and in the event of marked displacement possibly also the vessels along the neck After total interruption of these vessels the head is only supplied by the vessels of the ligamentum teres which anastomose with the other groups but which are as a rule unable to supply more than about one quarter of the head Major or minor parts of the head depending upon the competence of the remaining blood supply will then undergo necrosis However rapid invasion of vascular connective tissue occurs from the cervical fragment A necrotic head may thereby become re vascularized and necrotic bony tissue will be replaced as in a free bone graft This is the process known as creeping substitution It is a lengthy process however and is far from always complete Therefore parts of the head may remain necrotis The re vascularization must be assumed to have the best conditions after satisfactory reduction and fixation of the fracture (Phemister 1939) Indeed this is an important pre requisite for union If left untreated a fracture through the neck of the femur will usually end in pseudarthrosis With the Whitmann method of conservative treatment the frequency of pseudoarthrosis was considered to be around 40 per cent (Speed 1935) After the introduction of hip nailing the frequency of non union is around 15 per cent (Spotoft 1944) There is no doubt however that the blood supply of the capital fragment must also influence the union of the fracture in this site as well as in others Thus when the blood supply to the capital fragment is reduced or abolished the chances of union must be considered more unfavourable although it certainly may occur despite necrosis of the head Therefore studies concerning the risk of capital necrosis must also be expected to afford some impression of the likelihood whether deficient union will occur

Radiological signs of capital necrosis occur late The first sign that has been described is increased density of the head as compared with the surrounding bones due to decalcification of the latter However it has been pointed out by Hulth (1961) that presupposing early mobilization the decalcification is slight or absent and that the increased density is due to new formation of bone during the process of re vascularization Indeed it has been demonstrated that in places bone trabeculae will undergo thickening because of bone formation on the surface of necrotic trabeculae (Bohr & Larsen 1965 Woodhouse 1962) Such thickening frequently occurs in patches in the femoral head

which thus acquires a heterogeneous radiological appearance. Owing to minor fractures in necrotic trabeculae, major or minor collapse may occur, especially in the upper capital segment, and this may be the first radiological sign of necrosis, often not visible until a year or two after the fracture.

Skeletal biopsies will show, but not until a week or two after the fracture, changes consisting in breakdown of cells, first in the bone marrow and later of osteocytes (Catto 1965). Barnes (1962) has emphasized that the only evidence of necrosis is collapse of the femoral head on the X-ray *film or necrotic changes found in microscopic examination of the entire head.*

Accordingly, it has been a matter of great interest for many years to arrive at tests which could determine, soon after the fracture, whether capital necrosis would occur in a given case. It applies to all such tests that at this early stage they can only indicate the likelihood that the clinical syndrome of capital necrosis is going to appear, as this does not happen until at a considerably later juncture. Any such method must be used on a sufficiently large material, and after a sufficiently long follow up period – at least two and preferably three years – the course must be analysed before the value of the method can be assessed.

A number of different methods have *been used for evaluating* the extent of vascular injury in fractures of the femoral neck in order thereby to assess the risk of avascular necrosis.

Arteriography has been described by inter alios Brünner et al. (1967), McGinnis et al. (1958), Mussbichler (1956) and Rook (1953). This method appears to be rather uncertain, and visualization of the small vessels within and along the femoral neck cannot be expected.

More use has been made of venography, injecting the contrast medium into the femoral head (Dahlgren 1959), De Haas & McNab (1956), Eberle (1964), Hulth (1956, 1958, 1965) and Hulth & Johansson (1962). Under normal conditions the contrast medium is rapidly absorbed, and X-rays visualize the afferent veins which accompany the course of the arteries, as demonstrated by Trueta & Harrison (1953). If the veins are interrupted, this filling does not occur, and the contrast medium will stagnate in the femoral head. Hulth felt that this method was so dependable that in such cases replacement arthroplasty should be performed primarily on elderly patients (Hulth 1956, 1962).

A large number of methods are *based upon* the use of radioactive isotopes. Two different principles may be used. In part the uptake by the femoral head of intravenously injected isotope may be determined

and in part the rate of elimination of the isotope from the head after it has been injected may be determined either by direct counting over the head or by determination of the activity in venous blood or over the heart These methods possess the theoretical advantage that they afford a certain quantitative measure of circulation in the head whereas a venography for instance can decide whether vessels have been preserved but affords no information concerning the extent of the blood supply

By various modifications of the former method P^{32} has been used first by Tucker (1950) later by Arden (1953 1960) Bloch & Georg (1962) Boyd et al (1955 1963) Massie & Stevens (1964) and others I^{131} has been used by Forgon (1966)

It is probably better however to determine the rate of elimination from the head of an isotope which is not taken up specifically by bony tissue To this end Na^{24} (Laing & Ferguson (1958 1959) and I^{131} have been used *inter alios* by Holmquist (1965) Johansson (1962 1964) and Laing & Ferguson (1959)

Substances other than radioactive isotopes may also be used in the same way e g dyes (Price 1962) and X ray contrast medium (Matumoto 1966) Woodhouse (1962) has also advocated a method for direct measurement of the oxygen tension in the femoral head

An entirely different method was described by Brucker et al (1965) When the circulation in the head has been interrupted changes in the enzyme systems of the cells occur within a few hours This is demonstrable histochemically by staining a bone biopsy

Simple determination of the course of the fracture line in relation to the head neck junction after reduction of the fracture may according to Piggott (1965) afford satisfactory guidance concerning the risk of necrosis

Lastly it may be mentioned that Soto-Hall (1964) has pointed out a little heeded factor viz the possibility of compression of otherwise intact vessels along the femoral neck due to intra articular accumulation of fluid after the fracture In his opinion this may lead to anoxia of the head He demonstrated that the intra articular pressure in hip joints with accumulation of fluid could in certain positions exceed the expected pressure in small arteries By means of animal experiments Woodhouse (1964) showed that an increase in intra articular pressure in the hip joint up to 50 mm Hg for 13 hours would invariably lead to capital necrosis

Summing up it may be said that none of the named publications has

afforded the solution of the problem, viz. of predicting the occurrence of complications, especially capital necrosis following fracture of the femoral neck by a method which is easy and devoid of risk. Many authors have studied only a few patients, and in a number of the investigations the follow up has been short and has included only a few of the patients. As a rule the accuracy is stated to be about 80 per cent. In addition most of the methods give, as may be expected, an appreciable number of unassessable results.

PRESENT INVESTIGATION

During the period January 1963 to March 1966 a total of 104 patients with fracture of the femoral neck were studied with respect to the blood supply to the head of the femur – at the outset by injecting I^{131} labelled albumin into the femoral head as described by O. M. Hansen in the Danish Surgical Society in 1963. Later, Xe^{133} was used in a major and I^{131} labelled antipyrine in a minor series of investigations.

The test was performed on all patients having fracture of the femoral neck proper except in cases of non operated wedged valgus fractures. In addition the study included all patients with trochanteric fractures which cannot be expected to affect the vascularization of the femoral head. This latter group was meant to be a kind of control group, although it must be realized that of course it cannot pass for a normal group. Among other things this group would be expected a priori to include a relatively large number of patients of advanced age and with osteoarthritis.

In two patients, one tested by I labelled serum albumin and one by I labelled antipyrine, the activity over the femoral head was so low that the result was not assessable. These patients were therefore excluded. Otherwise the test could be carried through in all patients and no complications could be ascribed to it.

Treatment was according to the current lines: reduction of the fracture and traction immediately at admission, operation by the method of Smith Petersen or McLaughlin being done a few days later.

Follow up

As already mentioned the follow up period required for analysing the incidence of complications should not be shorter than 2 years. Therefore patients who had not been treated in the meantime in the Department for complications of the fracture in the form of capital necro

sis or non union were followed as far as at all possible with a view to these complication for 2¼–4½ years As a large number of these patients are of advanced age many complicating diseases were present in particular senile dementia and debility Thus 4 patients with trochanteric fractures and 7 with transcervical fractures died during the primary stay in hospital Many died during the follow up period and several were too ill to be re examined For these reasons the subsequent course is known for only 52 out of the 104 patients

Apart from a general clinical examination the follow up study also included X rays of both hip joints A diagnosis of non union was made when the study disclosed secondary displacement and a still visible fracture line As a rule there was also severe absorption of the femoral neck and slipping of the nail A diagnosis of capital necrosis was made where collapse of the head was found apart from uneven structure or sclerosing In addition necrosis has been found in several cases histologically after removal of the head by secondary insertion of a Moore prosthesis

1 *I¹ labelled Serum Albumin*

Sixteen patients were investigated by injection into the femoral head of a serum albumin solution labelled with radioactive I^{131} in a dosage of about 20 micro Curie corresponding to a 0 3–0 8 ml solution There after the rate of elimination from the head was determined by direct counting over the head The half life of the I^{131} isotope is 8 04 days It emits beta and gamma rays The gamma radiation which has a great penetrating ability was measured with a scintallation detector coupled to a counter Prior to the test potassium iodide was administered by mouth for 48 hours in order to block the iodine uptake by the thyroid gland and this was continued during the test period In the first 11 patients the injection was carried out during the operation for the fracture The needle 14 cm long and 1 mm wide was introduced along a Kirschner wire inserted through the neck after X ray checking of its position in 2 planes In a few cases the needle was introduced through the nail canal after the osteosynthesis Any fluid was carefully collected in a separate swab Thereafter the activity over the femoral head was counted in the theatre and the locally remaining activity was determined by daily counting through 7–10 days The fall in the activity apart from that conditioned by the physical half life of I^{131} must be due to absorption from the site of injection and thus dependent upon the vascularization of the femoral head In calculating the

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whom the T/2 was highest and thus the circulation least satisfactory except for pseudarthrosis in one patient with a T/2 of 2 2 She was suffering from severe rheumatoid arthritis It was observed in several cases that patients with rheumatoid arthritis are particularly apt to develop complications after fracturing the femoral neck

2 *Xenon* [133]

The tests using I labelled albumin were extended over several days as this isotope is bound to a high molecular substance and is therefore slowly absorbed It was great simplification therefore when after the establishment of our clinical physiological laboratory where the tests were now performed we started using instead Xenon[133] at the advice of Dr O Munck

Xenon[133] is an indifferent gas It is rapidly eliminated from the organism with the expired air more than 90 per cent of the amount dissolved in the blood being excreted in a single passage through the pulmonary circulation Xenon [133] has a half life of 5 3 days and emits beta as well as gamma rays It was used in a solution of physiological saline injecting the femoral head with about 200 micro Curie corresponding to 0 2-0 4 ml of the solution The injection was in all cases percutaneous using Hulth s needle as described above Thereafter the gamma radiation was determined by a scintillation detector placed over the femoral head coupled to a counter and writer which recorded the counts per minute Plotting of time as the abscissa and activity corrected for the background radiation logarithmically as the ordinate gives an elimination curve which is – apart from the first 5 to 10 minutes – almost rectilinear The slope of this curve is considered a relative measure of the vascularization of the femoral head The half life T/2 gives a numerical expression thereof In these tests the counting could be restricted to about 50 minutes so that no regard had to be paid to the physical breakdown of the isotope

RESULTS

The Xenon [133] tests included 35 patients with trochanteric fractures and 45 hips with recent fracture through the femoral neck in 44 patients a 46-year-old woman having a bilateral fracture sustained in an epileptic fit

A *Trochanteric fractures* 35 patients from 31–91 years of age average 69 2 years

results a correction was made for the background radiation and physical breakdown of the isotope. Thereafter the half life of the injected activity was calculated. This quantity was called T/2 and was, as already mentioned, taken to be a relative measure of the circulation in the femoral head.

Of course this procedure necessitated a moderate prolongation of the operation and *it was a disadvantage to have to set up apparatus in* addition to that needed for the operation. Furthermore the actual object was to study the possibility of assessing the blood supply to the *femoral head before the operation. The last 5 patients of this series* and all of the subsequent ones therefore had the injection percutaneously into the femoral head. The injection was given through the needle described by Hulth (1958) which is introduced under local anaesthesia from the anterior aspect through a skin incision a few mm long just laterally to the femoral artery. Its position was checked by fluoroscopy with TV apparatus in the antero-posterior view. It is easy to feel when the needle enters the femoral head and thereafter it is pushed 1 cm *farther in. After removal of the obturator a thin needle was inserted* yet 1 cm deeper and through this needle the isotope was injected.

RESULTS

A. 8 patients with trochanteric fractures showed a T/2 of 2.9–11.3 days, average 5.6. Age does not appear to have influenced the result. Two of the patients had osteoarthritis. In these cases T/2 was 3.1 and 3.3, indicating a relatively ample vascularization.

Three of these patients were followed. The fractures had united, and there was no osteoarthritis or other complaints from the hip.

B. 8 patients had a fracture through the femoral neck. The T/2 *ranged from 2.2 to 12.1 days, average 5.5, with the same distribution* as in the trochanteric fractures.

Four patients developed complications: capital necrosis in two – T/2 6.5 and 6.9. Another two showed non-union and were treated with a Moore prosthesis. In both microscopic examination showed a *partially necrotic head although there had been no radiographic signs* thereof. In these cases the T/2 was 12.1 and 2.2.

Three showed at follow-up a united fracture without necrosis; in these cases the T/2 was 2.6, 3.3 and 6.0. *One had died at the time of* the follow-up study; T/2 6.3.

It will be seen then that complications occurred in those patients in

the femoral head in these patients This tendency corresponds to what was found in a study of osteoarthritic patients by I labelled albumin In both methods there was also a group among the patients with trochanteric fractures who had very little vascularization judging by the methods used in spite of the fact that these fractures could not be expected to affect the vessels supplying the femoral head

Follow up

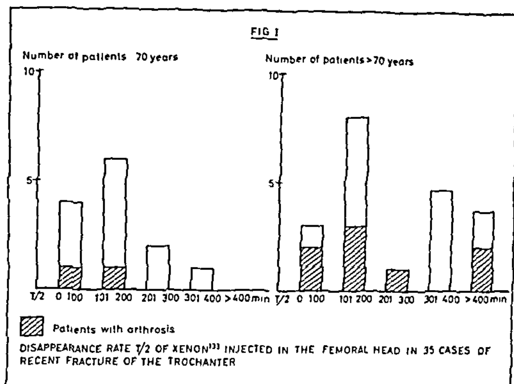
The subsequent course is known for only 13 out of the 35 patients In all the fractures had united and none had developed necrosis of the femoral head Only one had developed osteoarthritis which had not been present primarily and in another case osteoarthritis had become aggravated Strangely enough one patient with severe osteoarthritis involving severe symptoms had been almost relieved of complaints after the fracture with subsequent osteosynthesis

B *Transcervical fractures* 44 patients ranging in age from 44 to 89 years average 70 1 years i e the same average age as among the patients with trochaneric fractures Generally trochanteric fractures are reported to be most common among the oldest patients

The T/2 was from 30 minutes to ∞ average 150 9 minutes Figure 2 shows the distribution of the values plotted in the same way as in Figure 1

The mean T/2 in patients ≦70 years was 138 6 and in those over 70 years 164 6 minutes In other words this group too evidently showed a somewhat inferior vascularization of the femoral head in the oldest patients

Comparison with the values in the patients with *trochanteric fractures* shows very little difference This again agrees with the findings in the tests using I labelled albumin but is at variance with all previous studies and with what would have been expected *a priori* It would be expected that the group with fractures through the femoral neck were characterized by reduced vascularization that it would in other words show *higher T/2 values than the group with trochanteric* fractures in which the circulation in the femoral head would not be expected to be impaired A priori one would also expect a difference in the T/2 values according to *the degree* of displacement in fractures of the femoral neck However no such difference was demonstrable in the present material In greatly displaced fractures the T/2 averaged 149 7 and in two cases more than 400 minutes In moderately



DISAPPEARANCE RATE T/2 OF XENON[133] INJECTED IN THE FEMORAL HEAD IN 35 CASES OF RECENT FRACTURE OF THE TROCHANTER

The T/2 was highly varying from 39 minutes to ∞, i.e. during the test period of 50–60 minutes there was no decrease in the activity over the femoral head. T/2 was an average of 156 minutes. T/2 values exceeding 400 minutes being classified as ∞ and not included in the calculation of the listed means.

The numerical distribution may be seen from Figure 1 where the patients are divided into two groups ≦ 70 years and > 70 years of age. In addition patients with radiographic signs of osteoarthritis in the homolateral hip joint are indicated as according to the studies of Harrison et al. (1953) on the development of osteoarthritis in hip joints the femoral head in such cases must be expected to have a more ample circulation than in patients without osteoarthritis.

It is apparent that among the patients over 70 years of age there is a larger number with long half lives, i.e. presumed to have poor vascularization. Indeed the calculation shows that the group ≦ 70 years shows a T/2 averaging 131 minutes, whereas the over 70 group averaged 175 minutes. Ten patients, mainly elderly ones, had moderate to severe osteoarthritis in the homolateral hip joint. Despite a more advanced age the group with osteoarthritis showed lower T/2 values, an average of 119 minutes, indicating a more ample vascularization of

the femoral head in these patients This tendency corresponds to what was found in a study of osteoarthritic patients by I labelled albumin In both methods there was also a group among the patients with trochanteric fractures who had very little vascularization judging by the methods used in spite of the fact that these fractures could not be expected to affect the vessels supplying the femoral head

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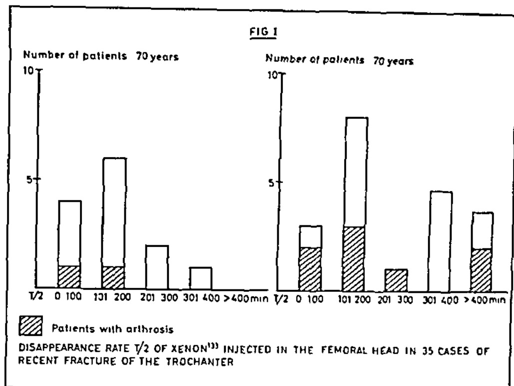
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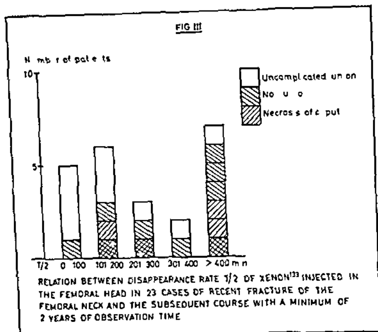


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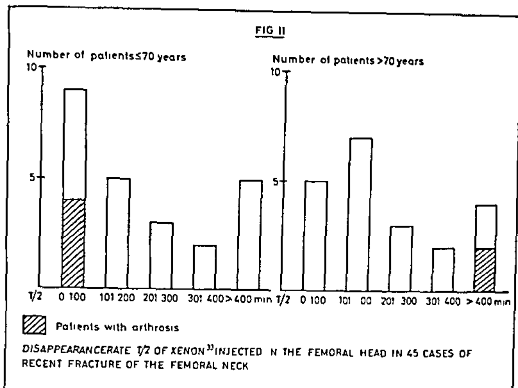
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RELATION BETWEEN DISAPPEARANCE RATE T/2 OF XENON[133] INJECTED IN THE FEMORAL HEAD IN 23 CASES OF RECENT FRACTURE OF THE FEMORAL NECK AND THE SUBSEQUENT COURSE WITH A MINIMUM OF 2 YEARS OF OBSERVATION TIME

ber with non union among the 37 primary survivors corresponds approximately to the actual incidence as re displacement is often already ascertained during the primary stay in hospital causing like pseud arthrosis considerable symptoms and a severely compromised walking function On the other hand capital necrosis gives rise to more delayed and often less severe symptoms Among the patients who died during the follow up period or among those who were not included in the follow up there were probably therefore some cases *of capital* necrosis It is worth emphasizing that two cases of necrosis were not detected until at follow up both with fairly modest symptoms and no previously unknown non united cases were discovered

It is obvious that the T/2 value affords no reliable guidance in respect to the occurrence of complications As might be expected the incidence is highest in the group where the vascularization is presumed to be poorest Among patients in whom the T/2 exceeded 400 minutes 6 out of 7 developed complications including necrosis in 3 whereas one fracture united without *complications* Reversely there were 3 cases of necrosis among those who were apparently well vascularized In two there was co-existent pseudarthrosis



DISAPPEARANCE RATE T/2 OF XENON[133] INJECTED IN THE FEMORAL HEAD IN 45 CASES OF RECENT FRACTURE OF THE FEMORAL NECK

and non displaced fractures the T/2 averaged 152 0 and in two cases it exceeded 400 minutes

Follow up

The course is known for 24 of the 45 fractures A patient in a poor general condition in whom the course had been stormy with severe pneumonia and cardiac arrest developed severe wound infection with osteitis and arthritis after the osteosynthesis In this case therefore the course cannot be assessed with a view to vascular complications of the fracture

Figure 3 shows the course after the remaining 23 fractures plotted against the T/2 values

From this figure it is apparent that among these patients there was a large number of complications mainly in the form of non union found in a total of 10 patients Three also had necrosis of the femoral head and another 3 developed necrosis of the head but the fracture had united

From these figures however nothing can be deduced concerning the absolute incidence of these complications Presumably the total num

mary treatment including reduction and application of traction An other factor too may be operative viz possible compression of the vessels due to accumulation of intra articular fluid (Soto Hall et al 1964 Woodhouse 1964) The measurements were not done until one or more days after the fracture when these factors must be presumed to have exerted their effect so that the vascular injury present at that juncture would be permanent It has been demonstrated in animal experiments by Woodhouse (1964) that necrosis occurred in all cases after 12 hours anoxia of the femoral head However the vascular injury may become aggravated during the operation For instance the insertion of the nail may cause major or minor vascular injuries in the femoral head presumably in the main of anastomoses from the vessels in the ligamentum teres which are usually intact and which may be decisive in supplying the head after interruption of the supply from other vascular areas At least it has been demonstrated by Sevitt (1964) that a wedge shaped area above the nail is frequently the seat of necrosis whereas Claffey (1960) found no major vascular injury not even where the tip of the nail was in touch with the fovea Naturally this possible cause of necrosis cannot be demonstrated in a pre operative investigation

A factor of uncertainty in the present method is the possibility that the injected fluid may escape through the puncture canal or the surface of the fracture to the hip joint After injection of X ray contrast medium the medium has been seen to distribute rapidly in the femoral head (Forson et al 1966 Hulth 1956 Matumoto 1966) and in some cases penetrates the surface of the fracture reaching the joint In such cases however the volumes have been several millilitres With the small volumes used in the present study i e 0 3 0 5 ml the escape into the joint must be assumed to be slight but in return the distribution in the femoral head is perhaps limited there being a possibility that it is deposited in a limited necrotic area which possibly may undergo complete revascularization This leads to the problem concerning the significance of revascularization We know that revascularization takes place and the extent to which it takes *place* must be of great importance to the clinical course Here again is a factor which cannot be assessed by tests done early in the course In this connection it may be mentioned that in autopsy *materials* the incidence of capital necrosis has reached as far as 80 per cent (Sevitt 1964) i e far exceeding the clinical incidence Therefore revascularization must be a decisive factor in many cases

In 4 out of the 10 cases with non-union the reduction at operation had been difficult or had not been fully satisfactory In 3 of these patients the T/2 was shorter than 400 minutes In the remaining cases the appearances at osteosynthesis cannot explain the occurrence of complications

3 *I^{131} labelled Antipyrine*

In a small series of a total of 8 tests I^{131}-labelled antipyrine was used The technique was the same as that of the Xenon tests and the results were expected to be in approximate conformity with these tests as the substance is low molecular and is not bound to bony tissue and not broken down in the tissues (Lindbjerg 1967)

A This series includes 3 patients aged 64 to 81 years with trochanteric fractures T/2 45 57 and 53 minutes Two of these patients had severe co existing osteoarthritis and at follow up 3 years later the third one had developed severe osteoarthritis in the hip

B *5 patients 59 to 91 years of age had transcervical fractures T/2* was 63 136 180 and 316 minutes and ∞ These patients with T/2 values of 136 and 180 minutes were seen at follow up The fractures had united without capital necrosis The patients having T/2 of 63 and ∞ had died at the time of follow up The patient with a T/2 of 316 minutes developed re displacement at the end of 4 months She was tested again and now the T/2 was only 54 minutes

DISCUSSION

The object of this study was to ascertain whether it was possible — by the present methods which proved easily practicable and devoid of complications — to separate *a priori* those patients in whom fracture of the femoral neck is followed by such compromised circulation in the femoral head that complications are sure to arise either in the form of capital necrosis or non union

A presupposition of using tests of circulation for this purpose is of course that *reduced circulation is the main cause of these complications* This is generally assumed in the case of capital necrosis The reduced circulation may be due to tearing of vessels in and along the femoral neck However Claffey (1960) has demonstrated that the lateral vessels along the femoral neck may be anatomically intact despite considerable displacement of the fracture In such cases clamping or kinking may be imagined to play a role and may presumably soon lead to thromboses In that event it is important to perform prompt pri

al (1953) which showed an increased vascularization of the head in osteoarthritis of the hip

2 In transcervical as well as in trochanteric fractures the vascularization of the head seems to deteriorate with advancing age

3 Among patients with trochanteric fractures too there was surprisingly quite a number with very slight vascularization of the femoral head judging by the present methods This might be assumed to be due to failure of the methods It must be emphasized at this site that in none of the cases was there a suspicion of misplacement of the needle in the test Incidentally Bloch (1962) in a study using intravenous administration of P^{32} in a small series of 6 trochanteric fractures found one patient with very slight vascularization of the head but he took it for granted that this must have been an erroneous determination Shermann & Selakowich (1957) reported that in apparently normal bones there might be major or minor necroses increasing in extent in the presence of peripheral vascular disease For instance he found subchondral necroses in the femoral head of an 86 year-old patient with a recent trochanteric fracture

4 The most surprising result is probably that the vascularization of the femoral head appears to be approximately the same after trochanteric and transcervical fractures although in the latter it would be expected to be more compromised due to vascular injury This finding seems rather inexplicable Is the reason that in fact the methods used do not afford any definite information concerning the circulation in the head? This appears to be improbable At any rate Xenon has been used with satisfactory results for determinations of circulation in other tissues with local injection and determination of clearance *inter alios* by Lassen et al (1964) and by Lindbjerg (1967) *also in* fatty tissue In this connection it must be borne in mind that the femoral head contains predominantly yellow bone narrow Another possibility is that perhaps the vascular injury does *not* affect the course as much as has been assumed In particular it might be imagined that the efficiency of the revascularization is the decisive factor

SUMMARY

Fracture through the femoral neck is followed by necrosis of the femoral head in about 25 per cent of the cases The explanation is assumed to be damage to the vascular supply of the head The vascularization of the capital fragment must also be assumed to *influence* the occur

It is even more difficult to predict the occurrence of non-union. In this respect, the accuracy of the reduction and the efficacy of the fixation no doubt play a decisive role. Casselbaum & Nugent (1963) felt that the course of union could be predicted with great accuracy on the basis of the operative result. However, lacking blood supply to the femoral head may be able to affect the course unfavourably. It is well known that fractures of the femoral neck may unite in spite of necrosis and that non-union may occur without necrosis, but frequently both complications co-exist. Gradually, as numerous pseudarthroses are being treated by prosthetic arthroplasty, it has been discovered that microscopic examination of the femoral head often shows extensive necrosis, although there have been no radiographic signs thereof. Indeed, this was observed in several cases of the present material.

All these theoretical reflections would play no major role if a method had been found for predicting the complications and if that method were in complete agreement with the course. However, this did not apply to the present technique. True, there was a preponderance of complications in the group in which vascularization was presumed to be poorest, but in one out of 7 cases the course was completely devoid of complications. Reversely, complications occurred in 7 out of the 16 better vascularized cases, predominantly in the form of non-union, but there were also 3 cases of capital necrosis. Thus, the method is not applicable as a basis for therapeutic indications. If 1/2 values exceeding 400 minutes in the Xenon test were considered an indication for primary prosthetic arthroplasty, several patients would nevertheless develop complications, a considerably smaller number of patients would be fitted with a prosthesis if the course without a prosthesis had been uncomplicated. In this respect it is a factor of importance how the patients with complications fare. It must be emphasized that a large proportion of the patients with capital necrosis, probably about half (Boyd 1963, Manninger et al. 1967, Spotoft 1941), manage tolerably, so that prosthetic arthroplasty is far from being necessary in all cases. It must also be borne in mind that all patients do not manage equally well with a prosthesis, even when it has been inserted primarily.

Thus, although the result of the present studies was negative when considered in the light of the primary approach, certain findings deserve to be emphasized.

1. Patients with osteoarthritis usually have ample vascularization of the femoral head, cf. the previously mentioned studies of Harrison et

al (1953) which showed an increased vascularization of the head in osteoarthritis of the hip

2 In transcervical as well as in trochanteric fractures the vascularization of the head seems to deteriorate with advancing age

3 Among patients with trochanteric fractures too there was surprisingly quite a number with very slight vascularization of the femoral head judging by the present methods This might be assumed to be due to failure of the methods It must be emphasized at this site that in none of the cases was there a suspicion of misplacement of the needle in the test Incidentally Bloch (1962) in a study using intravenous administration of P^{32} in a small series of 6 trochanteric fractures found one patient with very slight vascularization of the head but he took it for granted that this must have been an erroneous determination Shermann & Selakowich (1957) reported that in apparently normal bones there might be major or minor necroses increasing in extent in the presence of peripheral vascular disease For instance he found subchondral necroses in the femoral head of an 86 year old patient with a recent trochanteric fracture

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rence of non-union. If the occurrence of these complications could be predicted with reasonable accuracy the primary treatment could be decided accordingly, so that secondary prosthetic arthroplasty could be avoid. Various methods for determining the circulation in the femoral head have been tested, *inter alia*, arteriography, venography and in particular injection of radioactive isotopes either directly into the femoral head determining the elimination rate, or intravenously determining the uptake by the femoral head. The accuracy of the methods is around 80 per cent, but many results are unassessable.

The rate of elimination of radioactive Xenon[133] from the femoral head was determined in 45 cases of recent transcervical fracture and for comparison in 35 patients with trochanteric fractures. At follow-up a minimum of 2 years later, which included 23 out of the 45 cases of femoral neck fracture, capital necrosis and/or non-union were found in 6 out of 7 patients in whom the vascularization was presumed to be poor, but also in 7 out of 16 patients with satisfactory vascularization. Therefore the method is considered inapplicable as a basis for deciding the therapeutic indication.

Patients in whom osteoarthritis of the hip co-existed were found to have on the whole ample vascularization of the femoral head. After transcervical as well as trochanteric fractures the vascularization was less satisfactory in patients over than under 70 years of age. The degree of displacement of the transcervical fracture did not influence the vascularization. Strangely enough, a group of patients with trochanteric fractures, which are not supposed to affect the capital blood supply, were found to have a highly impaired vascularization, and on the whole capital vascularization was the same after transcervical and trochanteric fractures. This finding perhaps indicates that vascular injury is not as important an aetiological factor in these complications as previously assumed.

Smaller series were tested by injecting into the femoral head I[131] labelled albumin or I[131] labelled antipyrine by the same technique as used in the Xenon[133] studies, the results were the same.

ACKNOWLEDGEMENT

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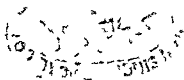
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EXPERIMENTAL DISC LESION IN RABBITS

The Effect of Repeated ACTH Administration

ENRIQUE HARRY HAIMOVICI

Received 25 vi 68

During the past thirty five years many works have been dedicated to the surgical and conservative treatment of acute disc lesions

All kinds of conservative methods from rest and plaster jacket to electrotherapy radiotherapy leg or pelvic traction spine manipulation ACTH and cortisone largactil (ampliactil) flaxedil and many other drugs have been tried and are still in use Haimovici 1959)

As a matter of fact we are ignorant of whether any of the various conservative means exert any direct influence on the histologic evolution of a disc lesion either in accelerating or delaying its healing

In order to shed some light on this problem it was decided to study the effect of repeated ACTH administration on the evolution *of* experimentally induced disc lesions

In the course of this experiment we observed that disc lesions *in* the animals used with or without ACTH administration revealed many striking peculiarities in the healing process which did not correspond to previous descriptions and therefore warrant this detailed report

MATERIAL AND METHODS

The material first consisted of a group of eleven rabbits weighing $1\frac{1}{2}$–2 kg each. The experiments were later repeated on a larger group of twenty five rabbits of similar size Three animals of the *first group* and one of the second group died during the experiment, three of them under *anesthesia* and one of unknown cause ten days after operation

Under general anesthesia with *ether* and sterile conditions the anterior aspect of the spine was exposed through a *left lateral longitudinal* abdominal subperitoneal approach Transverse incisions of $1\frac{1}{2}$ 2 cm were performed through the anterior aspect of the three lower lumbar intervertebral discs. The incisions *were*



Figure 2 Normal aspect of intervertebral disc in rabbit a annuplus fibrosus b nucleus pulposus e epiphyseal cartilage plates

RESULTS

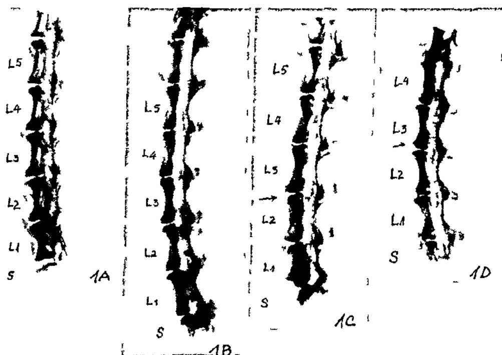
Macroscopical examination of the lumbar spine revealed scars at the place of incisions more or less indurated in consistency and adherant to the prevertebral muscles These scars were small but visible even in the thirteen day specimens The mobility of the lumbar spine appeared generally unchanged in all specimens In fact upon removal the lumbar spines inversed spontaneously from the usual kyphotic into a lordotic curve demonstrating that the anterior lesions and ensuing scars did not significantly restrain the flexion extension

The X ray pictures of the removed spines (Figures 1 A to D) did not show any remarkable narrowing of the intervertebral spaces Small anterior osteophytes could be seen on the X ray pictures of the thirty nine and fifty five day specimens (Figures 1 C and 1 D) from both the control and ACTH injected animals

Microscopical examination From four to six sections were prepared from every disc and a total of about 400 sections from 96 discs were examined The lesion in the annulus fibrosus was visible in the early and later sacrificed animals with more or less the same characteristics

carried through the entire thickness of the annulus fibrosus until the nucleus pulposus was seen emerging at the surface The wound was closed in layers and the animals were left to recover ACTH PROLONGAL (Cortrofina Z ORGANON) intramuscular injections of 10 units were administered to half of both lots of rabbits beginning the third day after operation The injections were repeated every second day during the first month and every third day during the second month

Half of both lots of rabbits served as control and did not receive ACTH after operation Both ACTH treated and control animals were divided in four groups according to time of sacrifice after the operation 13 26 39 and 55 days Four groups of eight animals four ACTH treated and four control were studied The total amount of ACTH received by each rabbit was 50 U by day 13 110 U by day 26 140 U by day 39 and 200 U by day 55 After sacrifice the lumbar spine was removed and examined macroscopically and X ray pictures were also taken The spine fragment was kept in formalin for at least ten days then decalcified and embedded in paraffin Microscopic sections were cut and colored with hematoxilin with specific coloration for the fibrotic and elastic tissues



Figures 1A to 1D X ray pictures of lumbar spines removed from rabbits Lesions of the intervertebral discs have been previously induced Figure 1A Fragment of the lumbar spine with thirteen day old lesion Normal aspect Figure 1B Twenty six day old disc lesion Normal aspect Figure 1C Thirty nine day old disc lesion Small anterior osteophytes between L2–L3 Numerotation L1 first vertebra beginning from the sacrum Figure 1D Fifty five day old disc lesion Small osteophytes particularly between L2–L3



Figure 2 *Normal aspect of intervertebral disc in rabbit a annuplus fibrosus b nucleus pulposus e epiphyseal cartilage plates*

RESULTS

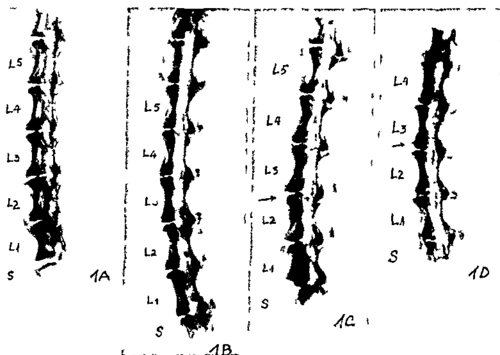
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Figures 1A to 1D. X-ray pictures of lumbar spines removed from rabbits. Lesions of the intervertebral discs have been previously induced. Figure 1A. Fragment of the lumbar spine with thirteen day old lesion. Normal aspect. Figure 1B. Twenty-six day old disc lesion. Normal aspect. Figure 1C. Thirty-nine day old disc lesion. Small anterior osteophytes between L2-L3. Numerotation: L1 first vertebra beginning from the sacrum. Figure 1D. Fifty-five day old disc lesion. Small osteophytes particularly between L2-L3.



Figure 2 Normal aspect of intervertebral disc in rabbit a annuplus fibrosus b nucleus pulposus e epiphyseal cartilage plates

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Figure 3 Intervertebral disc lesion thirteen days old of control rabbit a traject through annulus fibrosus b herniated cartilage blocking the lesion of the annulus fibrosus

The lesion resembled a traject formed by the cut lips of the annulus fibrosus connecting the cavity of the nucleus pulposus with the surface of the disc where herniated nucleus pulposus tissue could be observed (Figure 3) The described traject usually narrow and sometimes slightly enlarged was empty or contained fragments of nucleus pulposus The lesion was practically blocked in front by a thicker or thinner layer of cartilaginous tissue resulting from the herniated nucleus pulposus This latter tissue is known in normal disc to consist of a small number of large cartilaginous cells however after herniating outside the disc cavity its appearance was characterized by the presence of many small cartilaginous cells intruding into the cartilaginous fundamental tissue The explanation of this newly acquired appearance seemed to be that the young large cartilaginous cells of the nucleus while herniating react in two ways to the new conditions of pressure and nutrition through multiplication and degeneration Whereas the small cells are the result of multiplication the degenerated cells are represented by areas with many vacuolated cells (Figure 3 A)

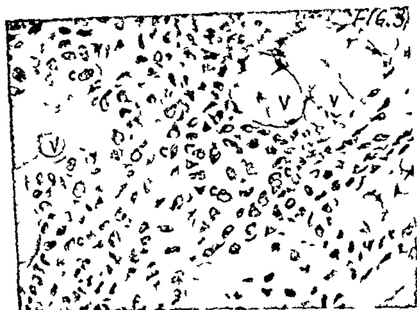


Figure 34 Higher magnitude (260 ×) of fragment from the herniated cartilage of previous picture c small cartilage cells v vacuolated cells interpreted as degenerating cartilaginous cells from the nucleus pulposus

The cartilaginous tissue covering the defect of the annulus fibrosus did not show any tendency to grow in thickness even after fifty five days However proximal and caudal growth corresponding to the lines of cleavage of the overlying tissues and directed toward the upper and lower epiphyseal cartilages is proved by the continuity established between the latter tissues and the herniated cartilage (Figures 5 A and 7 A)

The proliferation of the herniated cartilage derived from the nucleus pulposus was usually accompanied by a proliferative tendency of the anterior ends of the related epiphyseal cartilages (Figures 3 4 5 7 A)

This process was clearly seen in the twenty six day specimens

Islands of enchondral ossification were frequently seen on the thirty nine day and even on the twenty six day lesions Ossification was noted at the level of the related epiphyseal cartilage ends also as smaller or greater islands dispersed through the herniated cartilage (Figure 3 and 5 A)

Newly formed vessels could be observed in thirty nine day lesions and even earlier Localized and dispersed through the herniated



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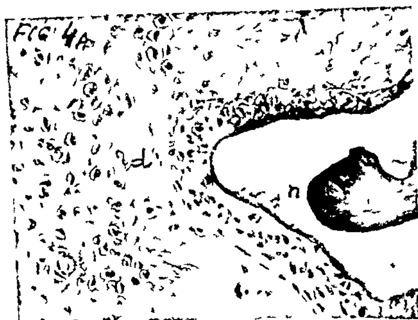


Figure 4A Higher magnitude (205 ×) of fragment (d) in Figure 4 Enchondral ossification of the herniated cartilage blocking the lesion of the annulus fibrosus

disc lesions the persistence of the nucleus pulposus could be observed as a large protruding tissue filling the opening in the annulus fibrosus and bursting outside without undergoing chondroid transformation after herniation at least in the central zone (Figures 6 and 6 A)

This means that there are two posibilities in the evolution of the disc lesions depending on the persistence of part of the nucleus pulposus or its entire chondroid transformation

DISCUSSION

Experimental disc lesions in animals have been studied and reported by Filippi (1935) in rabbits Key & Ford (1948) and Bercovici & Paraschivesco (1968) in dogs and Lindblom (1952) in rat tails

Bercovici & Paraschivesco produced disc degeneration by intradiscal injection of hyaluronidase (1958)

Lindblom fixed rat tails in the shape of U for various periods of time (1952) and succeeded in reproducing disc degeneration

Key & Ford (1948) used a posterior approach in dogs *in four*



Figure 4 Intervertebral disc lesion twenty six days after operation control rabbit Continuity is established between the herniated cartilage (a) and the anterior ends of the related epiphyseal cartilages (b b1) e blood vessels

cartilage they increased in number in the areas of enchondral ossification (Figure 7 A)

In most of the microscopic sections these vessels originating from the external structures penetrated into the herniated cartilage at the level of the anterior ends of the related epiphyseal cartilage

Fibrotic tissue was very poorly represented in all the specimens examined Usually the thirty nine day specimens showed a thick herniated cartilage covering the lesion of the annulus and establishing more or less continuity with the related epiphyseal cartilage ends (Figure 5)

However in a smaller number of specimens from thirty nine day


FIG 4A



Figure 4 Intervertebral disc lesion twenty six days after operation control rabbit Continuity is established between the herniated cartilage (a) and the anterior ends of the related epiphyseal cartilages (b b1) e blood vessels

cartilage they increased in number in the areas of enchondral ossification (Figure 7 A)

In most of the microscopic sections these vessels originating from the external structures penetrated into the herniated cartilage at the level of the anterior ends of the related epiphyseal cartilage

Fibrotic tissue was very poorly represented in all the specimens examined Usually the thirty nine day specimens showed a thick herniated cartilage covering the lesion of the annulus and establishing more or less continuity with the related epiphyseal cartilage ends (Figure 5)

However in a smaller number of specimens from thirty nine day



Figure 5A Same lesion higher magnification of the quadrant The islands of ossified herniated cartilage and the continuity between the latter and the epiphyseal cartilage are more clearly shown (b)

We did not observe any sign of a fibrocartilaginous regeneration of the annulus in our experiment The cut ends of the annulus always appeared inert without blood vessels and did not manifest any regenerative tendency following the lesion Such false impressions of regeneration or *restitution ad integrum* of the annulus were found when looking at microscopical specimens cut some distance from the lesion which therefore did not include the lesion

In our experiment the healing of the disc lesion proved to be a process involving especially on one side the herniated cartilaginous tissue deriving from the nucleus pulposus and on the other side the related ends of the epiphyseal cartilage In the first stage the defect in the annulus is covered by the herniated nucleus which undergoes a chondroid transformation The traject of the lesion is clearly visible This aspect was seen on the thirteen day lesions Around twenty six days the related ends of the epiphyseal cartilages begin to establish continuity with the herniated cartilage Signs of enchondral ossification are more evident in the thirty nine day lesions The enchondral ossification could be remarked as smaller or greater islands localized



Figure 5 Intervertebral disc lesion thirty nine days old from ACTH injected rabbit showing enchondral ossification (c) of the herniated cartilage (a) and continuity established between the epiphyseal cartilage (b) and the herniated cartilage (a)

intervertebral lumbar discs they inflicted lesions of various type and degree by puncture, incision excision and excision followed by vigorous curettage However they only described the results of disc excision followed by vigorous curettage which was the central problem of thier work At the beginning of our experiment we tried to use the posterior approach to the intervertebral disc in rabbits the same approach Key & Ford have used in dogs However the procedure proved very traumatic as it was necessary to remove most of the bone tissue due to the overlying laminae We therefore decided to reach the intervertebral disc through the anterior abdominal approach which proved easy and less traumatic and the animals recovered shortly after operation At this time we were not aware of the work of Filippi (1935) who had used a method in rabbits similar to ours and had produced similar lesions however he described the healing process following the sequence lesion granulation tissue fibrosis restitution fibrocartilaginous regeneration of the annulus beginning within twenty days and completed after forty days impaired mobility of the related vertebra and final *restitution ad integrum*



Figure 64 Same lesion seen with higher magnification

Generally the vascular structure reflecting inflammatory reactions of an articulation appears in the sinovial tissue The absence of sinovial tissue reduces the intervertebral disc to an avascular unit until advanced degeneration allows the penetration of small blood vessels into the annulus

Since disc lesion is reduced to avascular and low metabolic cartilaginous tissue intramuscularly administred ACTH could not reach high enough concentrations at this place to influence the evolution of the disc lesions In order to reach a high local concentration of hydrocortisone Feffer (1956) used direct intradiscal administration and obtained a definite clinical improvement in a considerable number of patients with disc lesions This action of hydrocortisone was explained as polymerization of the connective tissue polysacharides Further experiments are needed for a better understanding of the histologic changes following intradiscal hydrocortisone administration The observations in this experiment are valuable in understanding similar processes in humans Structurally the main difference between the intervertebral disc of the rabbit and the human (Coventry

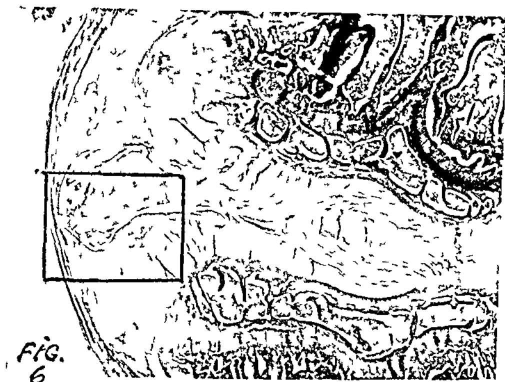


Figure 6 Unusual appearance of thirty nine day old intervertebral disc lesion of ACTH injected rabbit The large protrusion of the nucleus pulposus surrounded on its upper and lower sides by previously herniated cartilage gives the appearance of a fresh re herniation

in the central part of the herniated cartilage or near the related epi physeal cartilage ends

The animals which received small and even higher doses of ACTH did not present any considerable change of the described aspect and evolution of the disc lesions Previous studies concerning the action of ACTH/cortisone on articular processes were concentrated mostly upon rheumatoid effects Philip Hench (1951) described reduction of the cellular reaction with decreased numbers of plasma cells and lymphocytes reduction or absence of deposition of fibrin and lessened edema following ACTH/cortisone administration Coste Piguet Del bare & Bourel (1952) stated that the longitudinal growth of collagen fibers by apposition of structures is inhibited by cortisone R H Ramsay & Key (1955) on experimental talc arthritis in rabbits found the vascular dilatation element of inflammation quite diminished and there were fewer infiltrating phagocytes following cortisone No in fluence was observed on elastic fibers

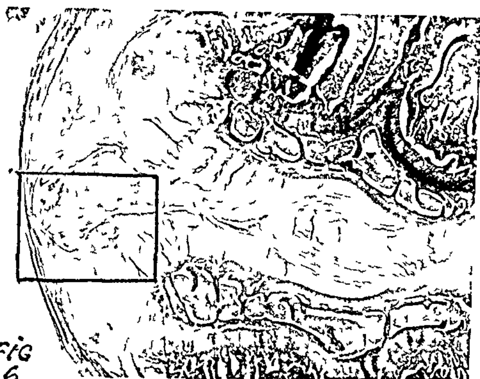


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Figures 7 and 7A Fifty five day old intervertebral disc lesion from ACTH treated rabbit showing enchondral ossification and the continuity of the herniated cartilage and the related epiphyseal cartilages

et al 1945) lies in the absence of the cartilage plates and reduced viscosity of the nucleus pulposus in rabbit (Figures 2 8 and 9)

In the rabbit the epiphyseal cartilages whose anterior and posterior ends are bent toward the intervertebral disc take part in the processes following lesion of the disc

The standing posture with the resulting increased pressure and strain over the disc peculiar to the human is nullified in the prone position Therefore we can conceive that the process of disc lesion in the human at rest follows a similar course as described in our experiment

Many anterior disc lesions such as we induced in rabbits may be



Figure 7B Same lesion at higher magnification showing the process of calcification and enchondral ossification of the herniated cartilage



Figure 8 Normal intervertebral disc from young human showing particularly the cartilage plates

observed among the low back pain patients and were verified by typical long lasting changes in the X-rays

The scars following disc lesions observed in our experiment were hard in consistency and adherent to the prevertebral muscles Although of reduced clinical significance when the lesions are anteriorly placed it is easy to understand the serious neurologic compression pattern arising when the lesion develops posteriorly in the narrow spinal canal with the nearby nerve structures

It is generally accepted that in most cases of acute disc conditions benign lesions may be found varying from a swollen disc with intact annulus—a practically reversible process—to a small partial annulus rupture healing through granulation tissue and fibrous scar when advanced degenerative changes of the disc are present at the time when the lesion occurs (Hirsch & Schajowicz 1952)

Complete rupture of the annulus fibrosus considered to be a rare occurrence was found by Feffer (1956) in fifteen of sixteen surgically explored cases in a material of fifty five well diagnosed acute disc lesion cases



Figure 9 Normal intervertebral disc of older human (Reproduced from Coventry Ghormley & Kernohan (1945b) J Bone Jt Surg 27 A 233-247)

In these fifteen cases he found complete rupture of the annulus fibrosus with free cartilage either in the canal or beneath the posterior longitudinal ligament This means that up to 27 per cent of the cases resistant to conservative treatment and selected for surgical explora tion may present a complete rupture of the annulus similar to the processes induced and studied in rabbits

SUMMARY

1 Lesions of the lumbar discs were produced and studied in rabbits

2 ACTH was administered to sixteen rabbits and another group of sixteen rabbits with similar lumbar disc lesions served as control The animals were sacrificed at intervals of 13 26 39 and 52 days after operation The total amount of ACTH received by each rabbit varied from 50 U to 200 U

3 No change of the lumbar spine mobility following the disc lesions was observed during the experiment

4 Small anterior osteophytes were revealed in the X ray pictures

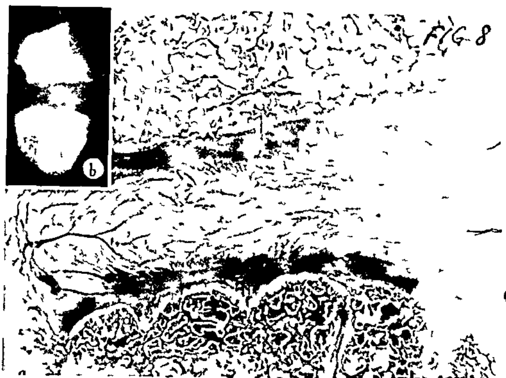


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of the lumbar spines from the thirty nine day sacrificed control and ACTH-injected animals

5 Healing of the disc lesions does not progress through granulation tissue fibrosis restitution *ad integrum*, as previously described by Filippi but only represents a process involving cartilaginous and osteocartilaginous tissues In the first stage the lesion of the annulus fibrosus is covered by the herniated nucleus pulposus reaching the aspect of a proliferating cartilage in the second stage the related epiphyseal cartilage ends manifest a proliferative tendency toward the herniated cartilage which may lead to establishment of continuity between both tissues a process of enchondral ossificatin at the level of the herniated cartilage characterizess the third stage

6 Repeated administration of ACTH did not lead to any visible change of the appearance and evolution of the disc lesions It is supposed that ACTH intramuscularly administered could not penetrate and reach high enough concentrations at the level of the avascular intervertebral disc to interfere significantly with the evolution of the disc lesions Such a condition may be corrected by direct intradiscal administration of hydrocortisone

7 Up to 27 per cent of well diagnosed acute disc lesions resistant to conservative treatment and selected for operation may present a complete rupture of the annulus whose healing process may reproduce the features described in rabbit

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EXPERIMENTAL OSTEOARTHRITIS IN RABBITS

Preliminary report

ANDERS HULTH LARS LINDBERG & HANS TELHAG

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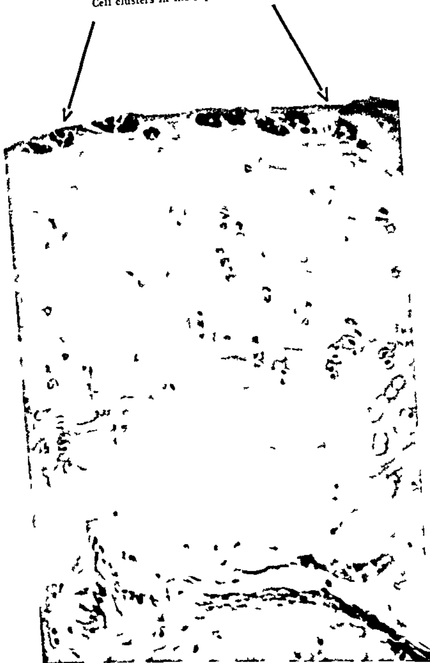
In earlier investigations where experimental degenerative changes of the joint cartilage have been studied these changes have been mostly induced by compression of the joint (Salter & Field 1960 Crelin & Southwick 1964 Ginsberg et al 1968) or by incisions in the cartilage (Carlsson 1957) These methods are more to compare to acute traumas than slowly progressing degeneration A method for inducing slowly progressing degenerative changes seems to be missing Mitosis has never been found in osteoarthritic joint cartilage of adult animals or humans The purpose of this investigation therefore was (1) to devise a method for producing a slowly progressing experimental osteoarthritis in rabbits and (2) to investigate with an autoradiographic technique if cartilage cells in osteoarthritic joint can divide by mitosis and if the so called cell clusters in osteoarthritic joint cartilage are formed by mitotic cell division

MATERIAL AND METHODS

The medial collateral ligament the medial meniscus and both cruciate ligaments were excised in the right knee joint of 28 adult rabbits The non operated left knee joints served as controls The animals were divided in groups of four which were

Financial support was obtained from the Swedish Medical Research Council Grants K68 17X 2436 01 and B69 14X 2552 01 and Herman Jarnhardts Stiftelse

Figure 1 Cell clusters in the superficial layer of the femoral knee joint cartilage 15 days after the operation Haemotoxin-eosin × 350



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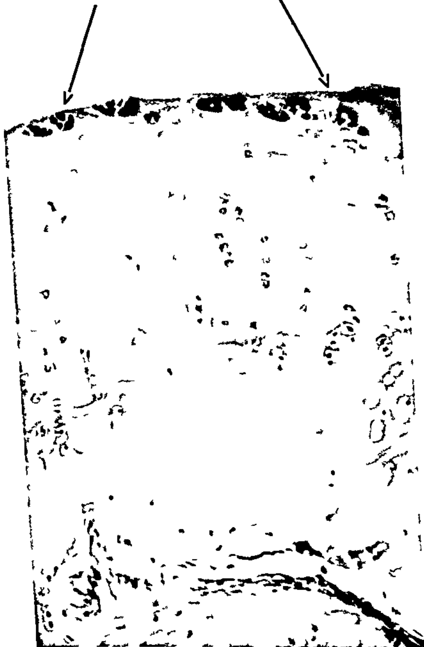
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F gu Flaking f the superf ial layer of the femoral knee joint cartilage 30 day aft the operation Ha matoxin eos n × 980

killed respectively 5 10 15 30 60 90 and 120 days after the operation Routine histologic sections were taken from the tibial and femoral ends of both knee joints

For the autoradiographic investigation 14 adult rabbits were operated according to the method described above Two animals were killed respectively 5 10 30 60 90 and 120 days after the operation Four hours before sacrifice 0 2 ml physiological saline containing 20 μCi tritiated thymidine was injected in both knee joints of each animal Autoradiograms were made with Ilford K 2 liquid emulsion on routine histological sections from both knee joints After exposure and processing the sections were stained through the emulsion with Mayers haematoxyline

RESULTS

Histologic Part

In this description the nomenclature suggested by Collins (1949) is used In the non operated control knee joints no pathological changes were found

In the operated knee joints no pathological changes were found until 15 days after the operation when the first degenerative changes i e derangement of the cell arrangement and formation of cell clusters began to appear in the superficial layer of the joint cartilage of both tibia and femur (Figure 1) After 30 days the clusters were more common and in addition some flaking of the superficial layer was now found (Figure 2) Ninety days after the operation the first signs of blistering were more conspicuous and moreover degenerative changes as derangement of the cell columns in the deep layer and cracks between the columns were also found (Figure 3) After 120 days all degenerative changes were still more advanced but in spite of this some parts of both the tibial and femoral cartilages appeared quite normal

At the present stage of the investigation it it not possible to describe the development of osteophytes but 90 days after the operation an increased amount of fibroblast like cells were seen in the capsular attachments and after 120 days fibrous cartilage with new bone formation was found in these areas indicating the formation of osteophytes

Audioradiographic Part

In the non operated control joints no labelled cartilage cells were found

In the operated joints a few labelled cartilage cells were found in the superficial layers of both the tibial and femoral joint cartilage

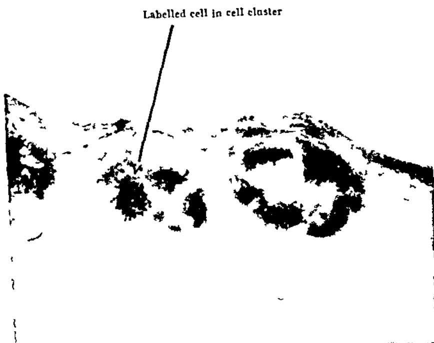


Figure 4 Labelled cell in a cell cluster in the superficial cartilage layer of the femoral knee joint cartilage 15 days after the operation Haematoxin eosin × 800

the cell clusters seen in osteoarthritic cartilage Crelin & Southwick (1964) have been able to demonstrate a few mitoses in the cartilage of compressed joints after treating the animals with colchicine but also an amitotic division has been suggested (Mankin 1963)

Only cells in the premitotic DNA replicating phase can be labelled with tritiated thymidine This labelling is a reliable mark that the labelled cell is going to divide by mitosis in the near future Thus the result of this investigation shows that mitosis is induced in the joint cartilage of adult animals at the same time as degenerative changes similar to those of osteoarthritis As labelled cells are also found inside the clusters it seems probable that the clusters are formed by mitotic cell division

SUMMARY

A method is described by which it is possible to elaborate a slowly progressing experimental osteoarthritis in the cartilage in knee joints



Figure 3. Blistering of the cartilage together with derangement of the cell columns and cracks in the deep layer of the tibial knee joint cartilage 2 months after the operation. Haematoxin eosin. × 70.

of one animal already five days after the operation. After 5–30 days labelled single cells were found in increasing amounts in both the superficial and transitional layers. After 60–120 days labelled single cells were also found in the deep layers in all animals.

Labelled cells appeared in the cell clusters as soon as these were found, i.e. 15 days after the operation in the superficial layer (Figure 4) and after 120 days even in the deep transitional layers (Figures 5 and 6).

DISCUSSION

Degenerative changes of the cartilage induced by this method develop much more slowly than those more acutely induced by the methods described by Salter, Crelin or Carlsson. The morphological changes induced are of the same type as those found in human osteoarthritis (Collins 1949). Therefore this method seems to be suitable for experimental model investigation on osteoarthritis.

As mitosis has never been found in articular cartilage of adult animals or humans (Mankin 1963), there has been some doubt about

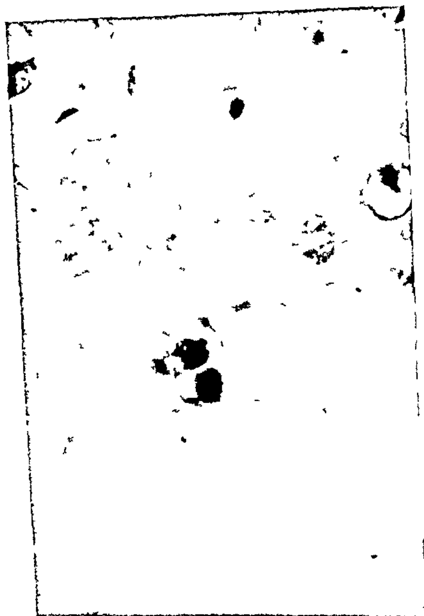


Figure 6 The same as in Figure 5 but in a higher magnification Haematoxin eosin × 800

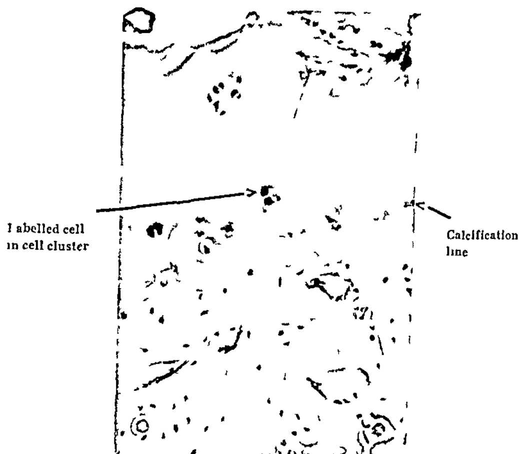


Figure 5 One labelled cell in a cell cluster in the deep cartilage layer of the femoral knee joint cartilage 3 months after the operation Haematoxin eosin × 300

of adult rabbits By using this method and autoradiography with tritiated thymidine it has been possible to show that mitotic cell division is induced in cartilage cells in osteoarthritic joints

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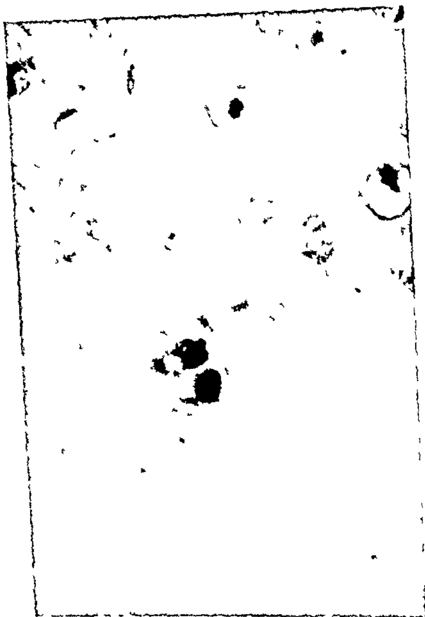


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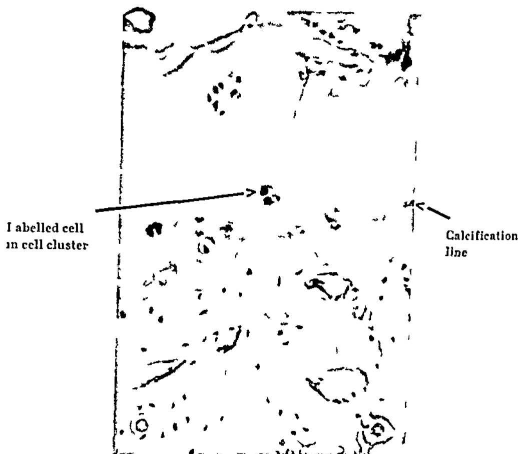


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BONE FORMATION IN HUMAN OSTEOGENESIS IMPERFECTA, MEASURED BY TETRACYCLINE BONE LABELING

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Received 1 70

The disabling and occasionally fatal skeletal disease known as osteogenesis imperfecta (OGIM) (synonyms brittle bones osteopsathyrosis Lobstein s disease) manifests itself in part by an insufficient quantity of bone in the skeleton associated with a mechanical fragility which may lead to numerous and repeated fractures some following minimal trauma and some occurring spontaneously As a consequence of these fractures plus an inability to model deformed bones in the normal way serious skeletal deformities frequently develop (Aegerter & Kirkpatrick 1968 Caniggia et al 1958 Rubin 1964) This condition has been attributed to an inability of osteoblasts to manufacture bone as fast as the growing fetal and infant skeleton required it (Aegerter & Kirkpatrick 1968 Caniggia et al 1958) Lacking direct evidence to the contrary this straightforward hypothesis has gained wide acceptance as the probable explanation for the skeletal features of OGIM The advent of tetracycline bone labeling (Milch et al 1958 Lee 1965) and the development of techniques which use it to measure the dynamics of bone formation directly in bone tissue now make it possible to study bone formation dynamics with greater certainty and accuracy in humans afflicted with metabolic bone diseases This article summarizes this laboratory s experience with measurements of bone formation rates in humans with OGIM as revealed in bone biopsies by the tetracycline bone labeling phenomenon

MATERIALS

This study includes 11 patients (7 males and 4 females) with obvious OGIM who contributed 12 biopsies of 12 bones. Three of these patients were reported previous

Mankin J H (1963) Localization of tritiated thymidine in articular cartilage of rabbits III Mature articular cartilage J *Bone Jt Surg* 45 A 529
Salter R B & Field P (1960) The effects of continuous compression on living articular cartilage An experimental investigation J *Bone Jt Surg* 42 A 31

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BONE FORMATION IN HUMAN OSTEOGENESIS IMPERFECTA, MEASURED BY TETRACYCLINE BONE LABELING

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The disabling and occasionally fatal skeletal disease known as osteogenesis imperfecta (OGIM) (synonyms brittle bones osteopsathyrosis Loebstein s disease) manifests itself in part by an insufficient quantity of bone in the skeleton associated with a mechanical fragility which may lead to numerous and repeated fractures some following minimal trauma and some occurring "spontaneously As a consequence of these fractures plus an inability to model deformed bones in the normal way serious skeletal deformities frequently develop (Aegerter & Kirkpatrick 1968 Caniggia et al 1958 Rubin 1964) This condition has been attributed to an inability of osteoblasts to manufacture bone as fast as the growing fetal and infant skeleton required (Aegerter & Kirkpatrick 1968 Caniggia et al 1958) Lacking direct contrary this straightforward hypothesis has gained s the probable explanation for the skeletal features nt of tetracycline bone labeling (Milch et al 1958 elopment of techniques which use it to measure formation directly in bone tissue now make it ation dynamics with greater certainty and l with metabolic bone diseases This s experience with measurements of with OGIM as revealed in bone eling phenomenon

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cretion yielded normal values None of the patients has a known associated renal endocrine nutritional or hematological disorder All arose from Caucasian stock.

METHODS

(1) *Labels and biopsies* All patients received one or two orally administered tetra cycline labels and a bone biopsy was done more than one but less than three weeks after completion of the last marker of the 11th rib in nine patients and in two other patients of one or more of the long bones of the lower extremities samples of which were removed at the time of elective operation (usually the Sofield "shish ke bab") for correction of bony deformities Table 2 lists the bone(s) examined in each case

(2) *Sections and stains* Undecalcified accurately oriented complete cross sections of the bone samples were ground by hand under running water on the day of receipt of the specimen and stained as described *elsewhere (Frost 1969) At* least 3 sections per case were prepared (except Oe whose two plastic embedded sections were submitted already prepared by Dr King) and mounted in Harleco Synthetic Resin for permanent reference

(3) *Measurements* By means of blue light fluorescence microscopy the tissue level *bone formation rate* of new haversian bone made (as seen in thin cross ections) per mm³ of pre existing compacta on an annual basis, was *measured directl as described elsewhere (Frost 1969)* The mean distance between the mid dles of the two tis ue time markers for bone formation also was measured in each section of each case This distance divided by the labeling interval equals the *appositional rate* of new bone formation and reflects *bone formation* at the osteoblast level (Frost 1969 Villanueva et al 1966) See Figure 1

Table 2 presents the above data as well as age-comparable normal data both in absolute units and as percentages of age-comparable norm *since especially in* children the speed of bone formation varies considerably as a function of age

RESULTS

(1) *Tissue level bone formation rate* This rate averaged *i e 300* per cent ± 70 per cent (S E = 23 per cent) of normal for the group of 9 rib biopsies which differs significantly from normal (which in com parable terms averages 100 ± 30 per cent S E = 2 per cent) by inspection ($p < 0.5$)

Only one of these patients (I_s) demonstrated a really subnormal rate yet his depression still fell within one S D of his comparable norm

While normal standards for the human tibia and femur do not yet exist other studies indicate that in man their formation rates average 10 to 50 per cent of the values for the 6th and/or 11th ribs (Frost 1969) On this basis the value of this rate fell within the normal range in case B and exceeded normal in both bones examined in case O

Table 1 Osteogenesis imperfecta subjects

Code	Age	Sex	Clinical history
N_j	3	♀	Many spontaneous fractures in lower extremities Generalized osteoporosis No bone disease in family
I_s	13	♂	Three spontaneous vertebral collapses perfectly healthy until this Generalized osteoporosis blue sclerae *No history of bone disease in family*
O_l	13	♂	Several vertebral collapses deformed (R) femur multiple past fractures of long bones *Family history of* imperfecta
Cd	15	♂	Bilateral fractures femurs at birth apparently normal until age 10 then 8 fractures of long bones Osteoporosis dentinogenesis imperfecta mother has blue sclerae
Cq	24	♂	20 fractures by age 13 none since then Osteoporosis *No history of imperfecta in family*
I_t	28	♂	9 fractures from age 9 to 20 Bone biopsy diagnosed as idiopathic osteoporosis at another hospital Multiple compression fractures with marked generalized osteoporosis
Ae	30	♀	60 fractures until age 12 Family history of imperfecta
Af	51	♀	Multiple fractures Severe deformities lower extremities and kyphoscoliosis Family history of osteogenesis imperfecta blue sclerae otosclerosis
Ag	70	♀	Multiple vertebral collapses multiple long bone fractures and blue sclerae Spinal osteoporosis brother and sister have osteogenesis imperfecta
Bu	4½	♂	Multiple past fractures upper & lower severe deformities No family history
Oe	11	♂	Multiple past fractures Severe deformities of femurs and tibias No family history

The basic clinical data for each case in this study The code letters identify a given case and remain identical for that case in all publications from this laboratory

ly and eight were not Their ages ranged from 3 to 70 years Three of them were submitted through the generosity of J King M D (Toronto Canada) M Castle M D (Detroit U S A) and P Meuniere *M D (Lyons France) Table 1* summarizes the case material In all of these patients numerous determinations of serum calcium inorganic phosphate and alkaline phosphatase and of 24 hour urine calcium ex

Table 2 Histodynamic data in 11 cases of osteogenesis imperfecta

Code letter	Bone biopsied	OGIM (M) (microns per day)	Age comparable normal (M) 11th rib (microns/day)	Per cent of normal (M)	OGIM (Vf) (mm²/mm²/yr)	Age comparable normal (Vf) 11th rib (mm²/mm²/yr)	Per cent of normal (Vf)
N_j	11th rib	1 1	1 4 ±0 46	79	0 37	0 38 ±0 24	97
I_s	11th rib	1 4	1.3 ±0 43	108	0 096	0 21 ±0 15	46
O_1	11th rib	1 2	1 3 ±0 43	9?	0 76	0 ?1 ±0 15	362
C_d	11th rib	1 4	1.3 ±0 43	108	0 29	0 21 ±0 15	138
C_q	11th rib	0 94	1 2 ±0 60	78	0 21	0 067±0 037	313
I_t	11th rib	1 1	1.2 ±0 60	9?	0 22	0 067±0 037	3?8
A_e	11th rib	0 53	1 1 ±0.36	48	0 14	0 018±0 006	778
A_f	11th rib	0 63	0 90±0 30	70	0 097	0 036±0 012	269
A_g	11th rib	0 77	0 72±0.20	107	0 20	0 044±0 015	455
B_1	Femur	0 83	1 4 ±0 46	59	0 17	0.38 ±0 24	–
O_e	Femur	2 00	1 3 ±0 43	154	0 39	0 30 ±0 10	–
	Tibia	1 70	1 3 ±0 43	131	0 49	0.30 ±0 10	–

The data and the bones examined for each case M The appositional rate, expressed in microns per day V The bone formation rate expressed as mm² of new bone made per mm² of pre existing compacta on an annual basis The Table also lists the data for each case as the per cent of the age-comparable norm of the 11th rib biopsy site No adequate standard of normal bone formation rates exists for the femur and tibia in man but these rates usually range from 10 per cent to 50 per cent of the value in ribs

In nonparametric terms the probability that tissue level bone formation in OGIM proceeds at subnormal speed and that these data merely reflect a sampling problem in which 11 out of 12 bone samples were nonrepresentative falls below 001 Accordingly the elevation of the group carries high statistical significance

(2) *Appositional rate* This averaged 88 to 20 per cent of normal for the group of nine rib biopsies Unlike the tissue-level formation rate which may adopt characteristic but different values from bone to bone in the same skeleton the appositional rate tends strongly towards uniform values throughout any *given skeleton* (Frost 1969) For this reason one may properly compare the values found in the tibia and femurs to normal standards for ribs The appositional rate differed by more than one S D from the normal mean in only two of the 11 cases (cases A_e and B_u) whose values still fell less than 2 S D below their comparable norms The mean for all 11 patients equalled

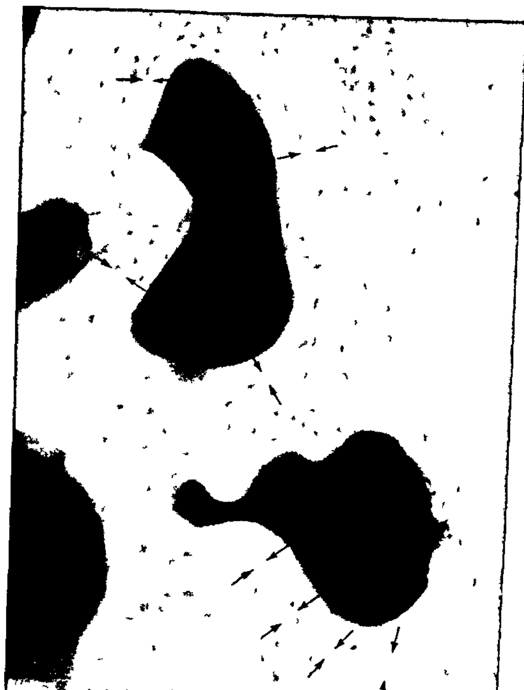


Figure 1 A photomicrograph of a 3–10–6 (double) tetracycline label in a child with osteogenesis imperfecta Undecalcified cross section 11th rib biopsy 370X blue light fluorescence We made four measurements of each labeled system at four intervals equally spaced around the perimeter of each the mean of all these measurements divided by the time between the middle of each marker represents the appositional rate of the text

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represent a dynamic abnormality which could account for the deficiency in bone mass which characterizes OGIM Note that this study did not define in any way the *quality* of the bone produced it measured only the *rate* of its production

(2) *Tissue level bone formation* Tissue level bone formation represents that made by the average osteoblast multiplied by the number of these cells in a unit amount (here one cubic millimeter) of bone At this level of biological organization the group s bone formation rate averaged 309 per cent *supernormal* and only one case had a subnormal rate Thus at this level too no justification appeared to explain their subnormal skeletal masses as an inability to make new bone as fast or in such amounts as body growth generally requires This statement even applies to the one case with a subnormal bone formation rate for again in vitamin D resistant rickets much greater depressions in this rate have accompanied normal if indeed not supernormal accumulations of skeletal mass (Frost 1969)

Interestingly Lee (1965) has reported very similer cell level and tissue leve lfindings in two young children with osteogenesis imperfecta whom he examined

Accordingly and contrary to former belief patients with osteogenesis imperfecta apparently can and do make new bone in adequate amounts at both the cellular and tissue-levels By the process of elimination this suggests that an inability to *retain* new bony tissue constitutes the cause of the subnormal bone mass which characterizes its disease i e too much bone resorption exists an excess which furthermore manifests itself primarily on the periosteal cortical endosteal and trabecular surfaces as reflected by the thin cortices and sparse amounts of spongiosa but relatively normal cortical porosities which characterize the skeletons of imperfecta patients A preliminary analysis of the patterns of anatomical distribution of this defect suggested (but did not prove) that periosteal and endosteal bone *cells may* respond to abnormal "signals in their local microenvironment signals which ultimately arise from mechanical forces acting on a skeleton whose structural material incorporates some qualitative abnormality which causes it to generate the abnormal signals (Ramser et al 1966)

(3) The present study illuminates only one aspect of the manifold features of OGIM that of the deficient accumulation of total bone mass It does not shed any obvious light upon the abnormal staining properties of decalcified sections of osteogenesis imperfecta bone

OSTEOGENESIS IMPERFECTA

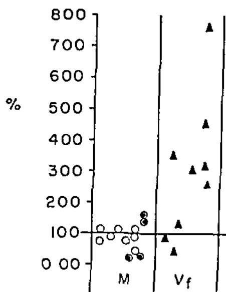


Figure 2 The values for the appositional rate and bone formation rate of each case were normalized by expressing each as the per cent of his or her age comparable norm M was normalized for all 11 cases and 12 bones but the formation rates were normalized only for the 9 rib biopsies since normal values of this parameter differ in characteristic ways in different bones of the skeleton

91 ± 31 per cent (S E = 6 3) of normal In comparable terms normal equals 100 ± 30 per cent S E = 2 per cent

(3) Figure 2 presents the above data in scatter plot form after normalizing each case to his or her age comparable norm (Frost 1969)

DISCUSSION

(1) *Cellular level index* We define cellular level bone formation as the average amount of new bone made by the average osteoblast in unit time Here the appositional rate serves as an index of this activity The appositional rate in these imperfecta patients fell within one standard deviation of normal in all but two of the 11 cases and 12 bones examined and lay above the mean normal value in five and below the mean normal level in six of the 11 cases Since much greater depressions in this parameter accompany perfectly adequate accumulation of skeletal mass during growth in vitamin D resistant rickets (Villanueva et al 1966) the small depression found here does not

represent a dynamic abnormality which could account for the deficiency in bone mass which characterizes OGIM Note that this study did not define in any way the *quality* of the bone produced it measured only the *rate* of its production

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(3) The present study illuminates only one aspect of the manifold features of OGIM that of the deficient accumulation of total bone mass It does not shed any obvious light upon the abnormal staining properties of decalcified sections of osteogenesis imperfecta bone

(properties which imply a qualitative defect in the organic matrix) nor upon the tendency to develop spontaneous' fractures nor upon the frequent association of dentinogenesis imperfecta and/or of oto sclerosis with the disease

SUMMARY

Both tissue level bone formation and an index of cellular level bone formation rates were measured in 11 patients with osteogenesis imperfecta The former averaged 309 per cent, the latter 91 per cent of normal These data indicate that at these levels the OGIM skeleton produces new bone in plentiful amounts By the process of elimination and from the purely quantitative point of view overactive resorption not deficient bone formation, should somehow cause the subnormal accumulation of skeletal mass which characterizes this affection

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ARTHROPATHY IN VON WILLEBRAND S DISEASE

Åke Ahlberg & Jorgen Silwer

Received 13 ii 70

Arthropathy is a common and often severely disabling complication of haemophilia A and B The incidence of joint lesions in a large series and its variation with the severity of haemophilia has been studied by Ahlberg (1965) and others The corresponding correlation in von Willebrand s disease has however received less attention Von Willebrand s disease is an autosomal dominant hereditary disease characterised by a low factor VIII (AHF) content and prolonged bleeding time (Nilsson & Blombäck 1963) Haemarthrosis and single cases of chronic arthropathy have been reported in patients with this disease (Nilsson et al 1957 Sánchez et al 1963 Corny 1965 Deshayes et al 1967)

This paper reports the incidence and types of joint lesions in a large defined population

MATERIAL AND METHODS

The material consisted of all known cases of von Willebrand s disease in Sweden (about 8 mill inhabitants) At present more than 400 patients belonging to 130 families are on the register The diagnosis in these cases has been made according to the criteria set up by Nilsson & Blombäck (1963) i e, prolonged bleeding time, low factor VIII and an autosomal hereditary pattern The disease is classified as severe if the Duke bleeding time exceeds 20 minutes and as *mild* if it is less than 20 minutes. In severe cases the AHF is 1 75 per cent of normal The present material included 32 patients with severe von Willebrand s disease The methods used for determining factor VIII bleeding time and platelet adhesiveness have been described previously (Nilsson et al. 1957 Silwer et al. 1964 Cronberg et al 1966)

In a related investigation of all the registered patients (Silwer) notes were made of any previous haemarthrosis and of other joint symptoms Patients who had reported such complications were subjected to orthopaedic (Ahlberg) and roent

(properties which imply a qualitative defect in the organic matrix) nor upon the tendency to develop spontaneous fractures nor upon the frequent association of dentinogenesis imperfecta and/or of otosclerosis with the disease

SUMMARY

Both tissue-level bone formation and an index of cellular level bone formation rates were measured in 11 patients with osteogenesis imperfecta The former averaged 309 per cent the latter 91 per cent of normal These data indicate that at these levels the OGIM skeleton produces new bone in plentiful amounts By the process of elimination and from the purely quantitative point of view overactive resorption not deficient bone formation should somehow cause the subnormal accumulation of skeletal mass which characterizes this affection

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Figure 9 R B Right ankle Marked subchondral cyst formation and sclerosis



Figure 3 R B Right elbow Sclerosis subchondral cyst formation narrowing of joint space and enlargement of rad al head

DISCUSSION

Haemorrhages in the joints and arthropathy are not predominant symptoms of von Willebrand s disease As expected they were found to vary in frequency and severity with the severity of the disease as judged from the bleeding time and the AHF content Haemarthrosis had occurred in about 40 per cent of the patients with severe von



Figure 1. R.B. Right knee. Marked sclerosis of bone ends, narrowing of joint space and osteophytes.

genographic examination. The severity of the joint lesions and the degree of disability were assessed according to Ahlberg (1965).

RESULTS

14 of the 32 patients with severe von Willebrand's disease reported that they had had bleeding in one or more joints. All had had haemorrhage in the knee joint. It had also occurred in the following joints in decreasing order of frequency: ankle, elbow and hip. The haemorrhages had been spontaneous or initiated by trivial trauma. Only in a few cases of mild von Willebrand's disease had there been symptoms of haemarthrosis and then after a more or less severe trauma.

Seven of these 14 patients had chronic arthropathy of varying severity with involvement of all together 7 knees, 5 ankles, 4 elbows and 1 hip.

The joint lesions consisted of increased trabeculation, sclerosis of the bone ends, subchondral cysts, narrowed joint space and osteophytes (Figures 1, 2 and 3). The surfaces of the affected joints were sometimes deformed (Figures 4 and 5).

with haemophilia the 32 patients with severe von Willebrand's disease were divided into two groups with an AHF of 1–4 per cent and 5–25 per cent respectively. The former group is comparable with patients with moderate haemophilia and contained 12 patients, the latter comparable with patients with mild haemophilia contained 20 patients. Five of the seven patients with arthropathy belonged to the former group and two to the latter. On comparison of joint score as a function of AHF level, mean number of affected joints per patient in various age classes and degree of disability, good agreement was found with the results obtained in Ahlberg's (1965) investigation of patients with haemophilia.

As in haemophilia the changes were dominated by early and advanced arthrosis. Subchondral cyst formation, trabeculation and sclerosis were often severe. There was no demonstrable broadening of the epiphysis of the knee and no genu valgum or varum. Neither did the patients show any squaring of the patella, i.e. a lesion typical of haemophilia. In affected elbows the head of the radius was enlarged (Figure 3) and the semilunar incisure was abnormally deep as in haemophilia (Figure 5).

CONCLUSION

The incidence and severity of joint disease in von Willebrand's disease vary with the severity of coagulopathy. Such lesions are rare in mild von Willebrand's disease. The joint changes are comparable in type, site and severity with those in cases of haemophilia with corresponding degree of coagulation defects.

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Figure 4 K A Left knee Deformity of the medial tibial and femoral condyles

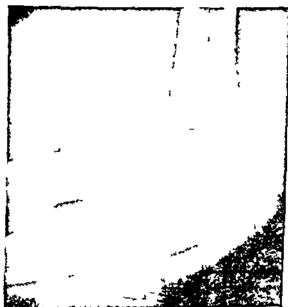


Figure 5 B H Left elbow Deepening of incisura semilunaris

Willebrand s disease and arthropathy in about 20 per cent These figures are not strictly comparable with those in haemophilia because in von Willebrand s disease the bleeding time and the AHF factor content vary more widely from one occasion to another and tend to improve with increasing age To enable comparison with patients

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Figure 4. K. A. Left knee. Deformity of the medial tibial and femoral condyles.

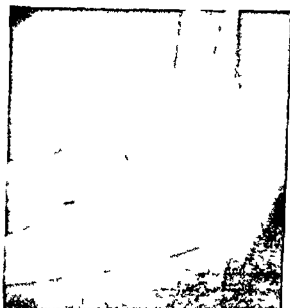


Figure 5. B. H. Left elbow. Deepening of incisura semilunaris.

Willebrand's disease and arthropathy in about 20 per cent. These figures are not strictly comparable with those in haemophilia because in von Willebrand's disease the bleeding time and the AHF factor content vary more widely from one occasion to another and tend to improve with increasing age. To enable comparison with patients

with haemophilia the 32 patients with severe von Willebrand s disease were divided into two groups with an AHF of 1–4 per cent and 5–25 per cent respectively The former group is comparable with patients with moderate haemophilia and contained 12 patients the latter comparable with patients with mild haemophilia contained 20 patients Five of the seven patients with arthropathy belonged to the former group and two to the latter On comparison of joint score as a function of AHF level mean number of affected joints per patient in various age classes and degree of disability good agreement was found with the results obtained in Ahlberg s (1965) investigation of patients with haemophilia

As in haemophilia the changes were dominated by early and advanced arthrosis Subchondral cyst formation trabeculation and sclerosis were often severe There was no demonstrable broadening of the epiphysis of the knee and no genu valgum or varum Neither did the patients show any squaring of the patella i e a lesion typical of haemophilia In affected elbows the head of the radius was enlarged (Figure 3) and the semilunar incisure was abnormally deep as in haemophilia (Figure 5)

CONCLUSION

The incidence and severity of joint disease in von Willebrand s disease vary with the severity of coagulopathy Such lesions are rare in mild von Willebrand s disease The joint changes are comparable in type site and severity with those in cases of haemophilia with corresponding degree of coagulation defects

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Acta orthop Scandinav 41 545–550 1970

Department of Neurology and Orthopaedic Surgery Aarhus University

AN ELECTROMYOGRAPHIC STUDY OF *TORTICOLLIS MUSCULARIS CONGENITA*

C H Håkansson & C Mouritzen

Received viii 1970

The unilateral affection of musculus sternocleidomastoideus in patients with torticollis muscularis congenita often combines with a cranial asymmetry concave to the side of the affection and with an elevation of the shoulder on the affected side Whether this is secondary to the affection of the sternocleidomastoid muscle or is due to an involvement of the facial and the trapezoid muscle on the same side is still a matter of dispute The sternocleidomastoid and the trapezoid muscle originate from the same branchial archs and this may indicate a common affection of the muscles from a primary involvement of the branchial arch (Lidge et al 1957)

However this does not explain the affection of the facial muscles unless the development defect is supposed to be neurogenic (Schubert 1926) with a congenital defect in the nuclei of the accessorius and the facial nerves which lie near each other

In 19 infants with congenital torticollis Baxter et al 1961 compared the electromyographic findings during full effort with histological findings The motor unit activity was normal or slightly diminished in 5 patients moderately diminished in 10 and severely diminished in 4 The degree of destruction of muscle fibers was related to the loss of fibers as indicated by electromyography *Tonnis* (1964) studied the duration amplitude and shape of motor unit potentials In 2 of the 10 patients he examined the trapezius muscle in addition to the sternocleidomastoid In 7 patients with advanced torticollis the duration and amplitude of motor unit potentials were reduced and the incidence of polyphasic potentials was increased The two trapezoid muscles showed no electromyographic involvement and he considered congenital torticollis to be a primary developmental defect of the sternocleidomastoid muscle

The aim of the study presented in this report is to contribute to an

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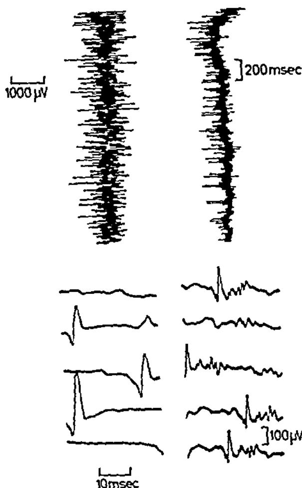


Figure 1 Electromyogram in a patient with congenital torticollis Above Pattern of activity during full effort Below Randomly sampled motor unit potentials Right Affected left contralateral sternocleidomastoid muscle

pattern in 7 with a reduced amplitude as compared to the contralateral side In 4 the reduction in amplitude was 30–80 per cent they had an advanced wasting of the muscle Five patients showed a mixed pattern indicating loss of some motor units (Figure 1) Fibrillation potentials or other types of spontaneous activity did not occur except when the patients kept the head straight when rhythmic bursts of motor unit activity occurred at a frequency of about 12 per sec

elucidation of the pathogenesis of congenital torticollis by an electromyographic study of the sternocleidomastoid, trapezius and facial muscles

MATERIAL AND METHODS

The study comprised 31 patients 16 males and 15 females 8–59 years old 18 less than 20 and 13 more than 20 years old Congenital torticollis facial asymmetry or other congenital diseases occurred in the near family of 8 patients In 24 patients there was a slight facial asymmetry and in 10 a slight asymmetry of the shoulder girdle One patient had a congenital eye disease

In 29 patients the sternocleidomastoid mucles were examined on the affected and the contralateral side and in 27 patients in addition the trapezoid muscles The facial muscles (m frontalis m orbicularis oris and m triangularis) were investigated in 19 patients In 16 patients electromyography was performed 4–18 years after a tenotomy

Recording The leading off area of the platinum core of the concentric electrodes was 0 07 mm² and the external diameter of the cannula 0 65 (DISA 13K03) and 0 45 mm (13K50) Their impedance was 50kΩ< —45° at 150 Hz and 7kΩ<—40 at 5000 Hz measured in saline with a voltage of less than 10 mV A 3 channel electromyograph (DISA 3A) was used for recording two channels connected to two electrodes inserted in the muscle of the affected side the third channel connected to an electrode inserted into the contralateral muscle The patients were examined horizontally and in a resting position Recordings from different motor units were obtained by inserting the electrodes in three different points of the muscles and at each point in three different depths In the facial muscles recordings were made from only two points in each muscle The pattern of activity and its amplitude during full effort was studied when the patient was asked to activate the right and left muscle simultaneously and then by asking the patient to turn the head against resistance to the right and to the left The average duration of a representative number of individual motor unit potentials and their average amplitude was determined during slight voluntary effort as was the incidence of polyphasic potentials These paramenters were evaluated according to the criteria described by Buchtal (1957)

RESULTS

Sternocleidomastoideus muscle In 8 of the 13 patients in whom a tenotomy had not been performed full effort resulted in an interference

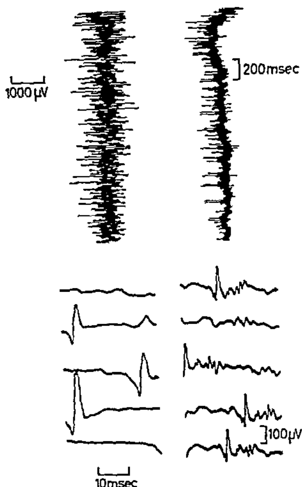


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Table 1 Electromyographic findings in the sternocleidomastoid muscles in patients with congenital torticollis

Pt	Age years	Per cent difference) in mean duration	Per cent difference) in mean amplitude	Per cent incidence of polyphasic potentials affected side	not affected side
			not tenotomized		
PH	8	— 6	—10	14	14
PDA	9	—35	—22	20	17
FN	10	+ 2	—24	25	12
WN	10	—30	—61	17	13
JH	10	—45	—28	16	6
FH	10	— 2	— 3	25	0
VJ	11	0	—44	22	17
IBK	12	— 6	—32	25	14
BB	18	— 7	+ 7	14	7
JP	25	—19	—15	32	16
PM	32	+ 2	—10	17	5
DP	36	—42	—42	12	0
EN	42	+13	—15	19	7
			after tenotomy		
GR	11	—11	—12	11	11
HC	11	— 7	—49	0	0
KOI	15	—20	+ 9	23	23
LL	17	+ 9	—32	0	0
RV	18	0	+ 2	5	0
KB	18	— 4	—13	8	8
IR	18	— 2	—29	10	10
BD	19	—28	—60	10	0
GL	22	+ 6	— 7	18	0
KD	23	—31	—33	6	0
HP	25	—24	+ 9	23	23
GJ	26	—22	—29	0	0
IB	26	—27	—38	8	0
IP	33	—15	—19	13	0
GH	33	— 2	+15	10	5
COV	59	+10	+13	8	7

) between the affected and the non affected side
) of all randomly sampled motor unit potentials

The mean duration of motor potentials was 13 5±per cent shorter in the muscle of the affected side than in the contralateral muscle and the mean amplitude was 23±9 per cent decreased The incidence of polyphasic potentials averaged 20±1 5 per cent in the muscles of the affected side as compared to 10±1 7 per cent in the contralateral muscle (Table 1)

In 16 patients in whom a tenotomy of the sternocleidomastoid muscle had been performed years ago there was an interference pattern with full effort in 8 patients a mixed pattern in 7 and discrete motor unit activity in 1 The amplitude of the pattern of activity was reduced in 7

The mean duration of motor unit potentials was 10±3 5 per cent shorter in the muscle of the affected and tenotomized side than in the contralateral muscle and the amplitude of randomly sampled motor unit potentials was 15±5 per cent lower Polyphasic potentials occurred in 9±2 per cent of all potentials in the muscles of the affected side in 6±2 per cent in the contralateral muscles (Table 1)

Trapezoid muscle In 17 of the 27 patients studied there was an interference pattern during full effort and in 10 a somewhat reduced degree of activity The average duration and amplitude of randomly sampled motor unit potentials were the same in the muscle of the affected side as in the contralateral muscle The incidence of polyphasic potentials was 7±1 5 per cent compared to 2±0 5 per cent in the contralateral muscle

Facial muscle In 19 patients studied the pattern of activity during full effort and the duration and amplitude of randomly sampled potentials were the same in the muscle of the affected side as in the contralateral muscle whether or not there was a facial asymmetry

DISCUSSION

The interference or mixed pattern of decreased amplitude in the sternocleidomastoid muscle of the affected side as well as the diminished duration and amplitude of motor unit potentials and the increased incidence of polyphasic potentials are consistent with the assumption of a primary myogenic origin of the congenital torticollis Baxter et al (1961) and Tonnis (1964) have reported similar findings they related the electromyographic changes to the increased proliferation of connective tissue observed in biopsies from the affected sternocleidoid muscles

Randomly distributed loss of muscle fibers and their replacement by

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From the 3rd Orthopaedic Department of Asklepion Orthopaedic Hospital
Athens Greece

CONGENITAL DISLOCATION OF THE HEAD OF THE RADIUS

E I Exarhou & N K Antoniou

Received 11 iv 70

Congenital dislocation of the head of radius not associated with other skeletal deformity or syndrome is a rare condition We consider this as an entity of its own that has also to be distinguished from congenital recurrent dislocation of the radial head

Abbott (1892) was the first to report 9 cases of this condition its complete description however was in McFarland s article (1936) with 11 cases A few case reports of this deformity have been published (Bonncberg 1892 Powers 1903 Meng 1940 Rose & Thomas 1938 Magee 1947 Caravias 1957 Cockshott et al 1958)

England discussed 21 cases he had seen Recently E. E. Almquist et al (1969) found only 4 isolated congenital radial head dislocations among their 18 cases

We will present 3 isolated cases of the above condition describe their clinical and radiological pictures and the results of their treatment

REPORT OF CASES

Case 1 Male 18 years old skilled factory worker He presented a slight prominence in the outer part of the antecubital fossa causing him mild pain and discomfort since incurring a trivial injury to his elbow two months previously He insisted that this prominence was present since birth but without pain or significant functional difficulty of the elbow

On examination there was 20 restriction of the elbow flexion while extension and rotation of the joint were normal

X rays showed anterior dislocation of the radial head which appeared under developed and domed the upper third of the ulna being large and bent forward and radially (Figure 1)

Excision of the head of the radius was performed in order to eliminate the persisting pain The patient seen six months later already back at his work, had painless elbow but with the same range of pre-operative movements

connective tissue can account for the electromyographic changes Such changes can occur either secondary to a fibrositis on a vascular or inflammatory basis or to a defect in development The familiar incidence is in favour of the latter Doring (1939) reported a familiar occurrence in 15 per cent of patients with torticollis and found it often together with other malformations In 8 of our 31 patients there was familiar occurrence of torticollis or other asymmetries In 10 there was a shoulder and in 24 facial asymmetry in addition to the torticollis These asymmetries are probably secondary to the developmental defect since there was no electromyographic evidence of a reduction in activity in the trapezoid and facial muscles

SUMMARY

Electromyography of neck and facial muscles in patients with congenital torticollis showed a diminished duration and amplitude of the motor unit potentials as well as an increased incidence of polyphasic potentials in the sternocleidomastoid muscle of the affected side This is consistent with a myogenic affection of the muscle

There were no electromyographic abnormalities in the trapezoid and facial muscles The shoulder and facial asymmetry is considered to be secondary to the changes in the sternocleidomastoid muscle

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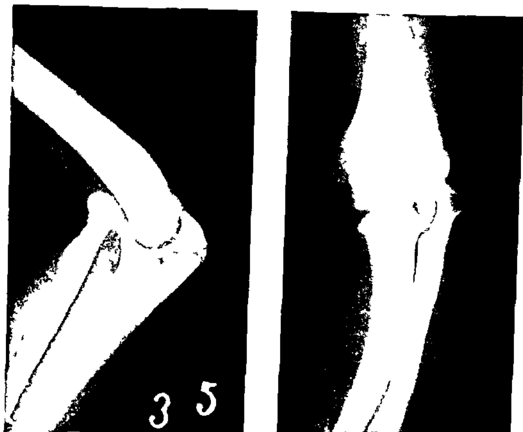


Figure 1 Case No 1 X rays of the anterior dislocated radial head which is underdeveloped Note the bowing of the upper ulna

Case 2 Child 3 months old was brought to us because of keeping the right forearm pronated since his normal birth. The head of the radius was palpable anterolaterally out of the normal place Passive elbow movements were full ex cept a 40 limitation of supination

On X ray the dislocation was confirmed and also the radius appeared long with its head higher than the radial notch of the ulna (Figure 2)

Close reduction was attempted without success and physiotherapy was rec ommended

One year later the elbow movements were normal but on X ray the dislocation was present

No treatment was advised

Case 3 Female 16 years old The parents reported that since her infancy she had kept her right forearm pronated and a painless click was heard on elbow move ments Since having lifted a heavy weight a few months before her admission the elbow had been painful

Clinically there was about 30 restriction of extetion and a click was heard on rotation

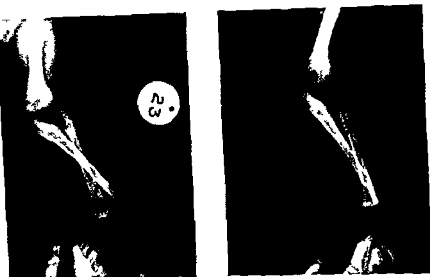


Figure 2 Case No 2 X rays of the elbows of the 3 month-old child.

X rays showed (Figure 3) anterior dislocation of an underdeveloped radial head flat capitellum and a posterior bowing of the upper ulna.

The radial head was excised and a cartilaginous loose body was also removed. At 18 months follow up she gained full painless movements

COMMENTS

Several hypotheses were forwarded as to the etiology of this malformation such as an hypoplastic capitellum (Osmond Clarke 1948) curvature of the ulna following an embryonic injury (McFarland 1950 Caravias 1957) or laxity of the annular ligament

We think the dislocation is a developmental defect and the above structural changes are secondary

The usual clinical findings consist of a very small limitation of the joint movements and slight deformity due to the dislocated radial head McFarland found little restriction of elbow movements in 5 of his 11 cases In all three of our cases the movements were only slightly limited

Apart from the dislocation which is usually anterior the X rays disclose a hypoplastic and domed radial head a dysplasic capitellum a posterior bowing of the upper ulna and increased length of the radius A few cases have been reported with calcification in front of



Figure 3 Case No 3 X rays show the anterior dislocation of the domed radial head and the increased length of the radius

the radial head These structural changes were present in our reported cases

Owing to the small deformity and the good function of the elbow we do not believe that treatment is advisable unless there is great limitation of flexion extension or persisting pain usually after trauma of the elbow as in two of our cases

Excision of the radial head is recommended in such cases in adults patients

In children physiotherapy is directed toward increasing the range of movements Closed reduction is not fissible and the successful open reconstruction of the joint would be a difficult surgical exercise involving shortening of the radius and annular ligament repair with doubtful results

SUMMARY

1 Three cases of congenital dislocation of the head of the radius are reported

2 In all our cases the dislocation was anterior causing slight deformity and little functional impairment of the joint

3 Resection of the radial head was performed in two patients because of persistent pain The restricted rotation of the forearm in the small child was greatly improved by physiotherapy

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A SIMPLE MEASURING DEVICE FOR HIP ARTHRODESIS

ANDERS WIGREN

Received 28 iv 70

For making accurate measurements of the degree of abduction and adduction in the position of the hip joint during arthrodesis there is a need for a simple easy to handle instrument which can be used throughout the operation The author has found no such instrument available and has therefore constructed an angle measuring device It consists of two parts (1) a 60 cm long bar with a protractor mounted at one end and (2) a bar the length of which can be varied as necessary which fits over two nails inserted one into each anterior iliac spine (see photograph)

To make a measurement the central hole in the protractor is placed

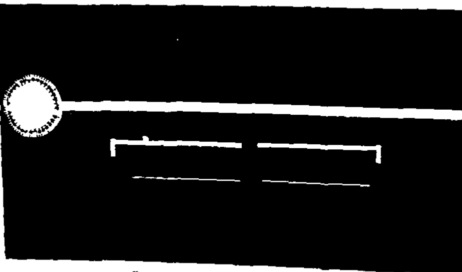


Figure 1 The parts of the instrument

The instrument will be marketed by KIFA

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Radiodiagnostic Department Östersund Sweden

FRACTURE OF THE FEMORAL NECK IN CASES WITH COXARTHROSIS ON THE AFFECTED SIDE

Leif T Östrup

Received 15 xii 69

If a patient with coxarthrosis obtains a fracture of the femoral neck on the affected side there seems to be a greater tendency to fracture of the trochanteric type than should normally be expected Thus Ståhl (1957) claimed that the combination cervical femoral neck fracture coxarthrosis rarely occurs Upon examining fifty cases of operated lateral (trochanteric) fracture however he recorded coxarthrosis in about 40 per cent of the cases

After analyzing a material of 1664 fractures of the femoral neck Alffram (1966) had the impression that trochanteric fractures predominate in cases with coxarthrosis He did not however penetrate the subject any further

This study is an attempt to illuminate whether there is a correlation between trochanteric fracture of the femur and coxarthrosis

MATERIAL

Radiographs of 440 cases of fracture of the femoral neck initial films as well as those taken later at operations were evaluated

During the 5 year period 1958–1962 a total of 536 patients with femoral neck fracture were recorded at the Radiodiagnostic Department Östersund Sweden Ninety six of these were excluded for various technical reasons missing or incomplete films poor quality etc

RADIOLOGY

The usual anteroposterior and "classical lateral views were used

The fracture In the classification of the fractures the author used the terms adopted by Alffram (1964) principally based on Faltin s



Figure 2 The instrument in position on a patient

on the nail in the anterior iliac spine of the side of operation The interspinal bar forms a fixed reference line throughout the operation The position of the leg can then be measured by use of the protractor bar Distally this is placed against a constant point of reference e g *the medial or lateral patellar border The angle between this bar and* the interspinal line is then indicated on the protractor scale

The measuring device can be used even with obese patients and allows for great variation in the distance between the iliac spines It does not encroach upon the operative field and causes no difficulty in the application of dressings or the use of radiological investigations The instrument has proved simple and easy to use and allows a good estimation of the position of the leg in relation to the interspinal line

Table 2 Fractures grouped according to sex and average age

	No of cases	Average age
Women	324	72 2
Men	116	69 4
Total	440	71 4

Table 3 Distribution of patients on fracture types

Type of fracture	No of cases	Per cent
Subcapital	151	34 3
Transcervical	155	35 ?
Trochanteric	134	30 ?

The predominance of left sided fractures often reported (Jensenius 1956 Alffram 1964) was not confirmed in this material (left sided fractures 218 patients right sided fractures 222 patients)

Table 3 shows the distribution according to fracture type 69 5 per cent of the fractures were cervical a somewhat higher frequency than in most previous published materials (Ibsen 1951 58 per cent Stewart 1955 43 per cent Alffram 1964 63 per cent) Yet Thorsoe (1960) found 69 per cent cervical fractures in his material

Coxarthrosis was found in 59 cases and the age and sex distribution of the patients in this group is demonstrated in Table 4

Table 4 Patients with coxarthrosis grouped according to sex and average age

	No of cases	Average age
Women	44	73 1
Men	15	71 5
Total	59	72 7

Table 5 shows the number of patients with moderate and severe coxarthrosis in the three groups of femoral neck fractures Nine out of eleven patients with severe radiographic changes in the hip joint suffered from trochanteric fractures

More than one fourth of the patients with trochanteric fracture had

classification (1924) (1) subcapital fractures (immediately below the head of the femur), (2) transcervical fractures (localized between this region and the base of the proper neck of the femur) and (3) trochanteric fractures (including Faltin s intertrochanteric and pertrochanteric fractures) Subtrochanteric fractures, occurring at the level of or below the lesser trochanter, were excluded

Stewart (1955) replaced the terms medial and lateral for the two main fracture types by the terms cervical (subcapital plus transcervical) and trochanteric

The coxarthrosis As shown by Danielsson (1964), osteophytes are part of normal age changes in the hip joint and have no clinical significance Osteophytes alone cannot be taken as a radiographic criterion of coxarthrosis

The diagnosis of coxarthrosis in this investigation has therefore been based on the demonstration of structural changes (hyperdensity cysts) and/or joint space changes (narrowing effacement)

For estimation of the severity of radiographic changes the author used *Herpret's scheme (Danielsson et al 1964)*, thus classifying the cases of coxarthrosis as 'moderate or severe

RESULTS

Tables 1 and 2 show the age and sex distribution of the patients The mean age in the material agrees with figures in previous studies (Bickel & Jackson 1950, Finney Jones & Eaton 1959 Alffram 1964)

The female male sex ratio was 2 8

Table 1 Age distribution of patients with fracture of the femoral neck

Age	No of cases	Per cent
20	0	0
21–30	1	0 2
31–40	8	1 8
41–50	17	3 9
51–60	49	11 1
61–70	107	24 3
71–80	149	33 9
81–90	96	21 8
91–100	13	3 0
100	0	0
Total	440	100

SUMMARY

1 In trochanteric fractures of the upper end of the femur arthrotic changes in the affected hip joint are found far more often than in fractures of the cervical type

2 Radiographs of 440 cases of femoral neck fracture were evaluated In 134 cases of trochanteric fracture arthrotic changes were found in the hip joint of the affected side in 26 1 per cent of the patients whereas in 306 cases of cervical fracture only 7 8 per cent of the patients had arthrotic hips Nine out of eleven patients with severe coxarthrosis sustained trochanteric fractures

3 Possible explanations of these findings are briefly discussed

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coxarthrosis, whereas only about 8 per cent of the patients with cervical fracture showed radiographic criteria of this disease.

Table 5. Occurrence and degree of coxarthrosis in the different fracture types

Type of fracture	Moderate arthrosis	Severe arthrosis	Per cent of cox-arthrosis
Subcapital	9	1	6.6
Transcervical	13	1	9.0
Trochanteric	26	9	26.1

DISCUSSION

It is evident that there is some connection between arthrosis of the hip joint and trochanteric fracture of the femoral neck on the affected side. The reasons for this are worth further consideration. A hypothesis was proposed by Ståhl (1957). While the *trochanteric* fracture seems to be due to extrinsic violence upon the femur, the *cervical* fracture, on the other hand, is probably in most cases the result of intrinsic forces, e.g. contraction of the external rotator muscles of the thigh with the extremity fixed in the orthostatic position (Smith 1953). In coxarthrosis the range of internal rotation is diminished and the resting position of the hip is in external rotation, giving rise to the characteristic rolled out position of the foot (Perkins 1961). This could mean that the external rotator muscles in these cases are too "short" to break the femoral neck, thus producing a cervical fracture. Further*more the inflammatory condition in the joint leads to increased mus*cular tonus, followed by bad nutrition, atrophy and fibrous degeneration. A reduction of the intrinsic forces is the result.

Another possible explanation: as a result of the peripheral proliferation in coxarthrosis with ossified excrescenses surrounding the fem*oral head at the margin* of the articular cartilage, the medial part of the femoral neck is reinforced. This is a hindrance to the occurrence of at *least the subcapital type of fracture*.

A combination of these theories might be the proper explanation of the phenomenon.

SUMMARY

1 In trochanteric fractures of the upper end of the femur arthrotic changes in the affected hip joint are found far more often than in fractures of the cervical type

2 Radiographs of 440 cases of femoral neck fracture were evaluated In 134 cases of trochanteric fracture arthrotic changes were found in the hip joint of the affected side in 26 1 per cent of the patients whereas in 306 cases of cervical fracture only 7 8 per cent of the patients had arthrotic hips Nine out of eleven patients with severe coxarthrosis sustained trochanteric fractures

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CLINICAL EXPERIENCE OF EPIPHYSEAL ARREST OF THE LOWER EXTREMITIES

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Differences in length between the lower extremities may be due to retardation of growth of one limb or overgrowth of the other (general review by Langenskiold 1957) In an adult correction of such a difference in length requires a comparatively large operation whether the intervention is shortening the longer limb or lengthening the shorter one Especially lengthening osteotomies are still accompanied by considerable difficulties even risks however tempting they may be in some cases Accordingly several methods have been developed in an attempt to correct during the growth period an existing and possibly still growing difference in length between the lower extremities (Goff 1960) In this stage too it is possible to strive for the end result by accelerating the growth of the shorter or retarding that of the longer extremity The safest method of retarding growth in length is to destroy surgically the epiphyseal cartilage and to make sure that the epiphyseal cartilage becomes ossified by making a bony bridge as was suggested by Phemister (1933) This procedure results in irreversible cessation of growth in the area in question and therefore it is especially important that it is done at the right moment In practice this means determination of the exact time in the growth period of the lower limbs after which the shorter extremity will have time enough to grow precisely the difference in length from the operated limb There are several formulas and tables available for this purpose (Green & Anderson 1947 1957 Tupman 1962 Nordentoft 1964) The operation presented by Phemister is usually performed on the distal femoral and/or proximal tibial and fibular epiphyseal cartilages because they account for the major part of the growth of

the lower extremity Seventy per cent of the growth of the femur stems from the distal epiphysis whereas the proportion of the proximal tibial epiphysis is 55 per cent of the total growth of the tibia (Tupman 1962) The term proximal tibial epiphyseodesis refers here to proximal epiphyseodesis of both tibia and fibula

The *purpose of the present study* was to find out from an analysis of the material of the Orthopaedic Hospital of the Invalid Foundation what clinical end results have been achieved with epiphyseodesis of Phemister type We tried to find answers to the following questions concerning the patients on whom this operation had been performed

(1) What were the clinically measured differences between the lower extremities at the time of cessation of growth in the patients operated?
(2) How did the presumed correction in accordance with the Green Anderson table agree with the obtained correction?
(3) How important is the determination of bony age in timing the epiphyseodesis?
(4) Is it important to perform orthoroentgenographic measurements when epiphyseodesis is being considered?

MATERIAL AND METHODS

The material comprised 65 patients For the sake of uniformity only patients on whom the epiphyseodesis had been performed in a clinically healthy extremity were included in the series (Grenshaw 1963) A clinically measurable difference was regarded as the most significant criterion in assessing both the original condition and the final result The measuring method used was largely indirect in other words boards of a fixed thickness were placed under the shorter extremity until the pelvis assumed a horizontal position This was complemented by direct measurement of the distance from the superior anterior iliac spine to the medial tibial malleolus with a measuring tape The measuring accuracy with both these methods in our estimation is of the order of 1/2 cm *The clinical measurement* was performed immediately prior to the operation and after cessation of growth of the lower extremities The presumed correction was calculated from the Green Anderson table (1947) Skeletal age was determined in 54 patients according to the Greulich Pyle tables (1947) and chronological age was used in only 11 cases *The operations were timed in accordance with skeletal age* when this was determined Orthoroentgenographic measurements of the length of the lower extremities were performed in 17 cases *and the values obtained were compared* with the corresponding clinical measurements

The growth period was taken to have ended in the lower extremities of the normal population in accordance with the investigations by Nordentoft (1964)

	Boys Age yrs /mos	Girls Age yrs /mos
According to chronological age	15/8	13/11
According to skeletal age	15/0	13/6

According to these values the growth of the lower extremities had ceased in all the patients in our series at the time of the last measurement.

RESULTS

Table 1 is a presentation of the entire series A major part 46 patients were suffering from late sequelae of poliomyelitis 12 had hemiatrophy and seven some other diseases which had made one leg shorter than the other

Table 2 presents the clinical end result in the various diagnostic groups and in the total series We considered the result to be good (I) if the ultimate difference in the length between the limbs was less than 2 0 cm The result was classified as fair if the difference was between 2 0 and 3 0 cm (II) and poor if the difference was over 3 0 cm (III) Accordingly good results were achieved in 66 per cent of the series This seems to be of the same order as the results of some other investigations (Morscher et al 1965)

An answer to the question how the Green Anderson table agrees with the attained correction is found in Table 3 The presumed correction according to the table is subtracted from the achieved correction and the difference is presented separately in the groups of under corrected exactly corrected and overcorrected limbs The number of undercorrected cases is considerably higher than the other two results In particular there are no overcorrections in the hemiatrophy group and undercorrection is clearly more common in this than in the other disease groups This is obviously because the hypoplastic non operated

Table 1 Material

Diagnosis	Number of patients
Sequelae post poliomyelitidem	4
Hypoplasia congenita extr inf	12
Coxa vara infantum	4
Hemiplegia spastica	1
Pseudoarthrosis colli femoris	1
Pes varus traumatica	1
Total	65

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(3) How important is the determination of bone age in timing the epiphyseodesis?
(4) Is it important to perform orthoroentgenographic measurements when epiphyseodesis is being considered?

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The growth period was taken to have ended in the lower extremities of the normal population in accordance with the investigations by Nordentoft (1964)

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Table 1 Material

Diagnosis	Number of patients
Sequel e post pol omyel tidem	45
Hypopl sia congen ta extr inf	12
Coxa vara infantum	4
He niplegia spastica	1
Pseudoarthros s colli femoris	1
I es varus traumatica	1
Total	65

Table 2. Clinical result (differences in length as measured with boards after cessation of growth) by disease groups

Difference in length between the limbs after cessation of growth	Disease groups: Sequelae post polio myelitidem	Hypoplasia congenita	Other diseases	Total
0 –1.9 cm (I)	29	8	6	43 (66 %)
2.0–3.0 cm (II)	12	2	0	14 (22 %)
Over 3.0 cm (III)	5	2	1	8 (12 %)
Total	46	12	7	65 (100 %)

limb ultimately did not grow the presumed amount, in other words progression of anisomelia was greater in this than in the other disease groups. It is obvious that in timing the epiphyseodesis at least in patients with hypoplasia it is advisable to use the amount of correction corresponding to the lowest value given for the age in question in the Green-Anderson table (1947). The same result was reached by Poirier (1968), especially in sequelae of poliomyelitis. However Blount's epiphyseal stapling method was used in his series in such a way that the Blount hooks were not removed until after the growth

Table 3. Achieved correction of the difference in length after cessation of growth minus presumed correction of the difference in length as determined according to the Green-Anderson table (1947)

	Sequelae post polio myelitidem: No. of pat.	Average under or over correct (cm)	Hypoplasia congenita: No. of pat.	Average under or over correct (cm)	Other diseases: No. of pat.	Average under or over correct (cm)	Total: No. of pat.	Average under or over correct (cm)
Under corrected	30	−1.5	10	−2.0	5	−1.5	45	−1.5
Exactly corrected	5	0	2	0	1	0	8	0
Over corrected	11	+1.0	0	–	1	+2.0	12	+1.0
Total	46	−0.5	12	−2.0	7	−1.0	65	−1.0

Table 4 Achieved correction of the difference in length minus presumed correction (difference in correction) in those patients in the poliomyelitis group whose skeletal age deviated from the chronological age (17 patients)

Patient no	Skeletal age minus chronological age (yrs)	Difference in correction when the skeletal age was taken into consideration (cm)	Difference in correction if the skeletal age had been ignored (cm)
3	+½	−? 5	−2 0
8	+1	+1 0	+0 5
20	+1½	−4 5	−8 0
1	−1	−2 5	−2 0
4	−½	+0 5	+2 0
13	−1½	−0 5	+3 0
16	−1½	− 5 5	−3 0
17	−1	0	+2 0
24	−1	−0 5	+1 0
28	−2	+0 5	+2 0
29	−1	0	+0.5
31	−1½	−3 5	−0 5
3?	−1	−1 0	0
35	−½	+2 0	−1 5
37	−1	−1 [illegible]	−0 5
38	−½	−1 [illegible]	−0 5
4	−1½	+1 0	+3 0

period was over In our own series the group consisting of sequelae after poliomyelitis clearly contained more undercorrected than exactly corrected or overcorrected cases The average undercorrection in the entire series is 1 0 cm Taking everything into consideration we think that the Green Anderson table is very useful in timing epiphyseodesis

Table 4 presents the patients whose skeletal age deviated from the chronological age In three patients the skeletal age was ahead of the chronological and in 14 it was behind it It can be seen from the Table how disregarding the skeletal age would have affected the correction A considerable overcorrection would have been the result in eight patients out of 17 if the correction had not been calculated in accordance with the skeletal age One weakness of the use of skeletal age is that its relation to chronological age is not constant Skeletal age approaches chronological age when the cessation of growth comes nearer as was stated by Green & Anderson (19?7) Especially because

Table 2 Clinical result (differences in length as measured with boards after cessation of growth) by disease groups

Difference in length between the limbs after cessation of growth	Sequelae post polio myelitidem	Hypoplasia congenita	Other diseases	Total
	Disease groups			
0 –1 9 cm (I)	29	8	6	43 (66 %)
2 0–3 0 cm (II)	12	2	0	14 (22 %)
Over 3 0 cm (III)	5	2	1	8 (12 %)
Total	46	12	7	65 (100 %)

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Table 3 Achieved correction of the difference in length after cessation of growth minus presumed correction of the difference in length as determined according to the Green Anderson table (1947)

	Sequelae post polio myelitidem		Hypoplasia congenita		Other diseases		Total	
	Disease groups							
	No of pat	Average under or over correct (cm)	No of pat	Average under or over correct (cm)	No of pat	Average under or over correct (cm)	No of pat	Average under or over correct (cm)
Under corrected	30	—1 5	10	—2 0	5	—1 5	45	—1 5
Exactly corrected	5	0	2	0	1	0	8	0
Over corrected	11	+1 0	0	–	1	+2 0	12	+1 0
Total	46	—0 5	12	—2 0	7	—1 0	65	—1 0

between the limbs after cessation of growth less than 2 0 cm) fair in 22 per cent (difference between 2 0 and 3 0 cm) and poor in 12 per cent

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of the obvious danger of *overcorrection* and *in the light of the present* investigation we consider that it is evidently necessary to take skeletal age into consideration in determining the time for epiphyseodesis.

Orthoroentgenography is regarded as important in determining the lengths of the lower extremities. However, it only measures the length as far as the distal joint surface of the tibia and differences in the length between the limbs due to differences in the feet are not taken into consideration. Primarily for this reason we used as the determining criterion the clinically measured difference and particularly the difference obtained by the so called board method. In order to elucidate how closely the clinical measurement corresponds to the radiological we compared the preoperative clinical measurements with the results of orthoroentgenography performed at the same time. We found that radiological measuring of the difference in length gave a higher result than clinical measuring in 24 patients, on average 0.5 cm. In 38 patients orthoroentgenography gave a smaller difference in length than clinical measuring, average 0.6 cm. In three patients the results were identical by both methods. The differences between radiographical and clinical measuring in determining the difference in length between the lower limbs are thus of the order of 1/2 cm, similar to the accuracy of clinical measuring. Since many physicians may perform the clinical measurements, the error may deviate considerably from the above mentioned averages. Hence orthoroentgenographic measuring is a very important control of length measurements of the lower extremities. In this respect we completely agree with Jansen (1957).

SUMMARY

The results of treatment of length differences of the lower limbs in 65 patients are analysed. The therapeutic procedure employed in all the cases was distal femoral and/or proximal tibial fibular epiphyseodesis (*Phemister*). *It was established that the Green* Anderson table is most useful in determining the optimal time for epiphyseodesis (Table 3). For patients with hemiatrophy it is advisable to use the smallest presumed *correction in the table* (Table 2). Determination of the skeletal age is important because of the obvious risk of overcorrection if it is disregarded (Table 4). Orthoroentgenographic measurement of *the length differences is* an important control of clinical measuring. The result was good in 66 per cent (difference in length

MATERIAL AND METHODS

Available for this study were 60 cervical fractures of the upper end of the femur with a diagnosis of necrosis of the head of the femur and/or pseudarthrosis of the neck All the cases had been followed roentgenologically for at least one year Cases in which a primary dislocation had resulted in prosthetic replacement or other such procedure before one year were excluded on the grounds that the diagnosis of necrosis or pseudarthrosis at such an early time could not be verified The average follow up time was 30 months

For comparison 56 cases were sampled with the same average follow up time 30 months during which time no roentgenographic evidence of complication had been noticeable

The films of these cases were reviewed with regard to

Primary displacement classified as total or non total depending on whether there was any contact between the fracture ends or not The primary displacement was also ranked depending on the angulation between *the fragments in two classes* < 20 and > 20 The maximum angulation was used whether measured *on* the antero posterior or the lateral film

Residual displacement after reduction *measured in degrees of* angulation on an antero posterior and a lateral roentgenogram

All fractures except for 12 had been reduced and pinned the procedure included the use of a television image intensifier

Twelve *impacted fractures* in this study were defined as fractures which were not operated on the grounds that they were considered stable and in which the fracture remained stable and maintained the degree of displ cement which was primarily observed

With regard to *fracture localization* the fracture types referred to in this study are demonstrated in Figure 1 Types 1 and 3 engaged the upper lateral *margin of* the femoral head where the lateral epiphyseal vessels enter the bone (Claffey 1960)

RESULTS

There was no significant difference in age between cases with and without complications (Table 1) The *primary displacement* had been worse in complicated fractures as compared to non-complicated (Table 2) The *residual displacement* did not differ significantly between com plicated and non-complicated cases The malposition measured on the antero-posterior as well as on the lateral roentgenograms was even somewhat although not significantly less in the complicated group (Table 3)

Reduction to a position without noticeable residual displacement had been significantly more frequently obtained in totally displaced fractures than in less displaced fractures (Table 4) Between the dif ferent types of fractures the complications were distributed as shown in Table 5 The fracture types 1 and 3 with involvement of the lateral

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THE EFFECT OF FRACTURE DISPLACEMENT ON LATE COMPLICATIONS IN FEMORAL NECK FRACTURES

Ake Carlsson, Per Edwards & Bo E Nilsson

Received 6 viii 69

The importance of technical perfection in the operative treatment of cervical fractures of the upper end of the femur has been debated Although it is clear that primary dislocation of the fracture following *surgery may result from a poor technique the opinions differ when it* comes to whether a poor reduction in the long run may cause necrosis of the head or pseudarthrosis of the neck of the femur Smith (1959) Garden (1961) Frangakis (1966) and others are in support of the concept of malposition after reduction and fixation as an important *cause of complications later on especially rotational and valgus position* have been considered to be unfavourable Claffey (1960) stressed that the site of the fracture was important involvement of the lateral superior edge of the head of the femur would interrupt the circulation in the lateral epiphyseal vessels and thereby cause necrosis of the neck of the femur However *Edholm Lindblom & Maurseth (1966)* failed to demonstrate any influence of malposition on the incidence of necrosis of the head of the femur

The object of the present study was to compare retrospectively primary displacement malposition after operation and internal fixation *the type of fracture and the age at fracture* between cases with and without complications

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Financial support for this study was obtained from the Swedish Medical Research Council (Grant No K69 23X 2737 01)

MATERIAL AND METHODS

Available for this study were 60 cervical fractures of the upper end of the femur with a diagnosis of necrosis of the head of the femur and/or pseudarthrosis of the neck All the cases had been followed roentgenologically for at least one year Cases in which a primary dislocation had resulted in prosthetic replacement or other such procedure before one year were excluded on the grounds that the diagnosis of necrosis or pseudarthrosis at such an early time could not be verified The average follow up time was 30 months

For comparison 56 cases were sampled with the same average follow up time 30 months during which time no roentgenographic evidence of complication had been noticeable

The films of these cases were reviewed with regard to

Primary displacement classified as total or non total depending on whether there was any contact between the fracture ends or not The *primary displacement* was also ranked depending on the angulation between the fragments in two classes < 20 and > 20 The maximum angulation was used whether measured on the antero posterior or the lateral film

Residual displacement after reduction measured in degrees of angulation on an antero posterior and a lateral roentgenogram.

All *fractures* except for 12 had been reduced and pinned the procedure included the use of a television image intensifier

Twelve *impacted fractures* in this study were *defined* as fractures which were not operated on the grounds that they were considered stable and in which the fracture remained stable and maintained the *degree of* displacement which was primarily observed

With regard to *fracture localization* the fracture types *referred* to in this study are demonstrated in Figure 1 Types 1 and 3 engaged the upper lateral margin of the femoral head where the lateral epiphyseal vessels enter the bone (Claffey 1960)

RESULTS

There was no significant difference in age between cases with and without complications (Table 1) The *primary displacement* had been worse in complicated fractures as compared to non-complicated (Table 2) The *residual displacement* did not differ significantly between complicated and non-complicated cases The *malposition* measured on the antero posterior as well as on the lateral roentgenograms was even somewhat although *not* significantly less in the complicated group (Table 3)

Reduction to a position without noticeable residual displacement had been significantly *more frequently obtained* in totally displaced fractures than in less displaced fractures (Table 4) Between the different types of fractures the complications were distributed as shown in Table 5 The fracture types 1 and 3 with involvement of the lateral

Table 1

	Complicated	Non complicated	
Age	67 7 ± 11 9 (SD)	65 5 ± 13 1	Non significant

Table 2

	Complicated	Non complicated	
Primary displacement			
Total	49	31	
Non total	11	25	0 01 > P > 0 001

Table 3

	Complicated	Non complicated	
Residual displacement (degrees)			
Antero post	4 8 ± 1 1	6 0 ± 1 1	Non significant
Lateral	3 1 ± 1 0	5 9 ± 1 3	0 1 > P > 0 05

Table 4

	Primary displacement		
Residual displacement	Total	Non total	
Noticeably displaced	34	18	
Not noticeably displaced	46	6	0 02 > P > 0 01

Table 5

Fracture type	Complicated		Non complicated
	Necrosis	Pseudarthrosis	
1	2	2	4
2	21	4	30
3	3	4	3
4	10	11	17
5	0	0	2

Table 6

Fracture type	Complicated	Non complicated	
1 + 3	11	7	
2 + 4 + 5	49	49	Non significant

Table 7 Impacted fractures

	Complicated	Non-complicated	
Non impacted	59	45	0 01 > P > 0 001
Impacted	1	11	

Table 8 Nail slipping

	Necrosis	Non complicated	
Slipping	18	19	
Non slipping	18	37	0 2 > P > 0 1

Table 9 Nail slipping

	Pseudarthrosis	Non complicated	
Slipping	18	19	
Non slipping	6	37	0 01 > P > 0 001

epiphyseal vessels were not significantly more frequently complicated than the remaining groups (Table 6)

There were significantly fewer impacted fractures among the com plicated cases than among the non-complicated (Table 7)

In 55 fractures nail slipping was observed This observation was significantly more frequent in cases who developed pseudarthrosis of the neck of the femur but not in cases with femoral head necrosis only (Tables 8 and 9)

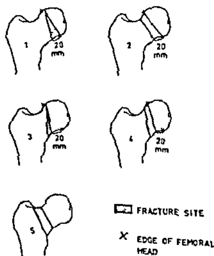


Figure 1 Types of fracture of the femoral neck

DISCUSSION

Advanced age has frequently been considered to influence union. The findings in the present study support the conclusion of Gardner (1961) that age is not of major importance for the final results in fracture of the neck of the femur.

The conclusion of Claffey (1960) that a certain type of fracture which engages the upper lateral epiphyseal vessels would give almost one hundred per cent of femoral head necrosis was not supported by the findings in the present study.

The position of the fracture after reduction and osteosynthesis seems similarly to be of no importance, on the contrary there is a tendency to the reverse. This may be explained by the fact that totally displaced fractures could more easily be reduced to a perfect position. The totally displaced fractures were also over-represented in the group of complicated cases. The conclusion must be that the fate of the femoral head is decided at the moment of the fracture. It should however be emphasized that a certain number of complications, not included in this study, depend on faults in the technical procedure which lead to dislocation of the fracture primarily or when weight bearing is commenced. After one year these cases have been sorted out and from this point the problem of viability and healing has little to do with the surgical procedure.

SUMMARY

The initial roentgenograms were reviewed in 60 cases of cervical fracture of the upper end of the femur who had developed pseudarthrosis or femoral head necrosis and compared to 56 cases with the same follow-up time who had not.

(1) There was no age difference.

(2) The complications could not be referred to any singular fracture type.

(3) The position after reduction of the fracture did not influence the outcome with respect to pseudarthrosis or necrosis.

(4) The initial displacement before reduction had been significantly worse in cases who had later on developed complications.

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The Orthopaedic Clinic University Hospital Lund Sweden
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PATELLA ALTA IN NON DISLOCATING KNEE JOINTS

HÅKAN BRATTSTRÖM

Received 30 ix 69

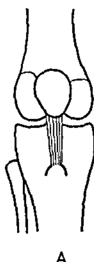
Patella alta (p a) or high standing patella has been referred to by many authors as one of the main causes of recurrent dislocation of the patella At extended knee and relaxed quadriceps muscle the apex of the patella in a normal knee is level with the joint line (Figures 1 A and B) The sides of the intercondylar groove of the femur give it bony support laterally and medially If the patellar ligament is abnormally long the patella will lie cranially to the entrance of this groove and lack this bony support (Figure 1 C and D) The patella will therefore become unstable sideways and may dislocate Consequently some of the most common operations for recurrent dislocation of the patella are partly directed against the high standing patella by transferring the tibial tuberosity—and the patella—distally (For survey see Brattstrom 1964)

Nowhere in the literature however is there any information to suggest that a patient with no history of dislocation will have symptoms from a high standing patella

The purpose of this article is to point out that a person with high standing patella may have symptoms without suffering dislocations and to stress that the position of the patella should be examined in patients with uncharacteristic knee troubles

DIAGNOSIS

To be able to make the diagnosis patella alta one must know the normal variation limits of the position of the patella The diagnosis is made difficult by the fact that as the condition is usually bilateral there is no healthy side with which to compare The matter is referred



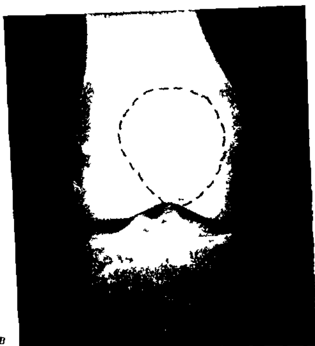


Figure 1 A and B Normal knee Apex patellae approx level with the joint line

to only rarely in current textbooks on anatomy rontgenology and orthopaedics and then it is stated that the apex of the patella is level with the joint line

The first to occupy himself with the diagnosis p a was Schulthess (1899) who described some spastics with high standing patella He pointed out that with the knee flexed at a right angle the patella normally sinks in between the femoral condyles and this produces a rounded contour of the knee (seen from the side Figure 2A) If there is a p a the patella appears as a protuberance of the femur and the knee contour is angular (Fig 2B)

By lacking bony support side-ways the patella can usually be passively moved laterally medially more than a normal one This abnormal mobility of the patella however is an appraisal based on the experience of the individual investigator

To determine the position of the apex by palpation may be difficult because it lies embedded in the ligament

X ray examination gives the definite diagnosis Blumensaat (1938) is to be given credit for having described the simple method which

C

D

Figure 1 C and D Patella alta apex above or level with the beginning of the intercondylar groove

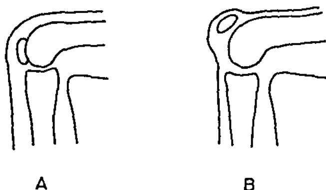


Figure 2 A Normally the patella sinks in between the femoral condyles at 90 degrees flexion This produces a rounded contour of the knee joint

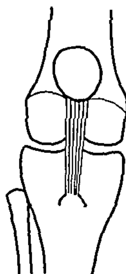
Figure 2 B Patella alta the patella appears as a protuberance on the ventral surface of the femur the knee contour is angular



Figure 3 A and B Normal knee Apex patellae on Blumensaat s line (see text) at 30 degrees flexion of the knee

though not fully exact (see below) is good enough for practical clinical work It is based on the following on an X ray *film* (lateral view) with the knee in 30 flexion a dense line can be seen formed by the ventral border of the intercondylar fossa (*Figure 3 A*) *If* this line is extended ventrally it will normally meet the apex of the patella (Figure 3 A and B) If the apex lies above this line a p a condition exists (Figure 3 C and D) This method was used by among others Thestrup Andersen (1955) in a large *investigation* of patients with recurrent dislocation of the patella He found that 207 out of 286 knee joints had p a However he *allowed for* the apex to lie 5 mm above this line before making the diagnosis p a (personal communication)

In order to test Blumensaat s method the *angle* u (Figure A A) which



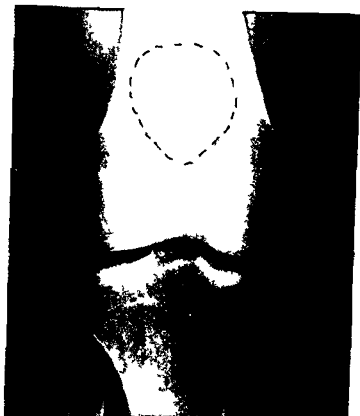


Figure 1 C and D Patella alta apex above or level with the beginning of the intercondylar groove



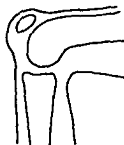


Figure 2 A Normally the patella sinks in between the femoral condyles at 90 degrees flexion This produces a rounded contour of the knee joint

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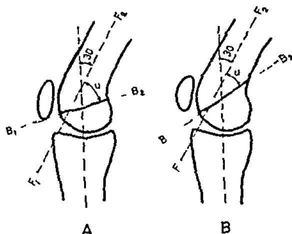


Figure 4 A Normal knee at approx. 30 degrees flexion F_1–F_2 Longitudinal axis of the femur B_1–B_2 Blumensaat's line u = the angle between F_1–F_2 and B_1–B_2 normally approx 45 degrees Apex patellae lies on Blumensaat's line.

Figure 4 B Knee joint at 30 degrees flexion The angle u is here approx 30 degrees (normally 45 degrees) This means that in spite of the apex being in its normal position i e level with the joint line it lies cranially of Blumensaat's line There is here a false patella alta

view makes it possible to diagnose a p a if corrections are made according to the foregoing

On the antero posterior view (extended knee) it must be known whether the quadriceps muscle has been contracted at the moment of exposure and the centring must have been towards the joint line (Figure 1D)

OWN SERIES

Since 1962 12 knee joints in 8 patients (4 female and 4 male) with pronounced symptoms have been classified as p a according to the X ray criteria referred to later on and excluding other conditions the symptoms referred to the abnormal position of the patella Surgery was considered necessary *in all* these cases They had no history of dislocation of the patella

The diagnosis p a was made in another 18 knees in 12 patients (5 female 7 male) but the symptoms were so slight that surgery was considered unnecessary these will not be discussed here

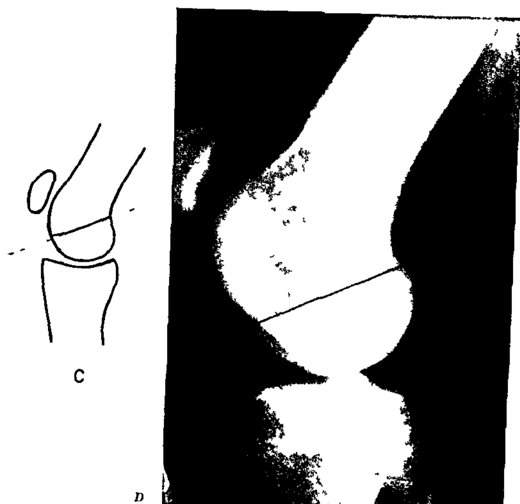


Figure 3 C and D Patella alta apex high cranially of this line

is formed between Blumensaat s line and the longitudinal axis of the femur was measured The angle was found to vary between 27 and 60 degrees (average 45°) in 100 randomly measured patients and as Figure 4 shows this suggests that Blumensaat s method is not fully exact It was found approximately that a reduction of the angle u of for instance 10° from the average value 45° to 35 meant that Blumensaat s line would go about 10 mm below the apex and a false diagnosis of p a may be made (Figure 4B) If on the other hand the angle u is for instance 55° the apex in a normal knee lies about 10 mm below Blumensaat s line

In most cases however Blumensaat s method is a good guide and this together with the position of the apex on the antero posterior

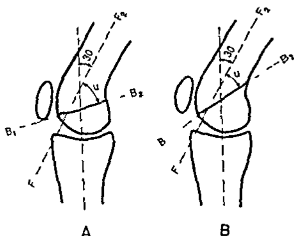


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Table 1 12 knees operated on under the diagnosis *patella alta*

Knee no	Sex	Age at op	Subjective troubled (besides ache)	Treatment	Results	Obs period (years)	Comments
1	f	10	Exudate	raphe of lig	excellent	5	same patient as no 2
2	f	10	Exudate catching	raphe of lig	poor	2	same trouble for 2 yrs then lux (see text)
3	f	12	Exudate catching (see text)	raphe of lig	excellent	7	see text
4	f	16	tired	transf of tub tib	excellent	5	same patient as no 5
5	f	17	tired insecure	transf of tub tib	excellent	3	see text
6	f	39	tired insecure	transf of tub tib	excellent	2	see text
7	m	26	tired see text	transf of tub tib	excellent	7	same patient as no 8
8	m	26	tired see text	transf of tub tib	excellent	7	see text
9	m	19	tired insecure	transf of tub tib	excellent	6	same patient as no 8
10	m	16	tired exudate	transf of tub tib	excellent	4	same patient as no 11
11	m	16	tired exudate	transf of tub tib	excellent	4	
12	m	38	tired insecure exudate	transf of tub tib	excellent	1	

Symptoms All patients have been bothered by aching and tiredness in the knee after walking and standing for a while In 6 knees there was recurrent effusion and in 4 knees a feeling of instability (but no dislocation) Two patients had noticed catching of the patella (see case nos 2 and 3 Table 1)

3 female patients complained voluntarily of the angular lumpy look of their knees

All 8 patients had bilateral p a and in 4 patients the symptoms made surgery necessary in both knees One patient with pronounced symptoms in one knee was almost symptom free in the other and 3 patients were completely free from symptoms in the other knee

Objective findings At the clinical examinations the pathological findings have been very few Four patients with symptoms in mainly one knee had an atrophy of the thigh on that side and in 3 knees an effusion was noticed In all 8 patients bilateral "angularity' (see above) was noted in the records and in 7 patients bilateral abnormal lateral mobility

No swelling of the joint capsule was registered Range of movement was normal and muscle strength 5 (according to the 0–5 grading)

Two patients (cases nos 3 and 4) walked with their knees in about 10 of flexion and refused to extend the knees fully

The ESR was normal in all patients

At X ray examination (antero-posterior view side view and axial view of the femoro patellar joint ad modum Knutson 1941) no pathological findings were observed apart from a high standing patella No femoro-patellar dysplasia (Knutsson 1941 Brattström 1964) was registered

In 6 knees an arthrography was performed with no pathological findings

For the diagnosis p a it was required in this series that the apex of the patella was more than 10 mm above Blumensaat s line (corrections made[1]) and on the antero posterior view (with the quadriceps relaxed) more than 20 mm above the joint line (femoral border) These generous limits were set to allow *for an unequivocal* diagnosis Proper guidance was given by the angularity and the abnormal mobility referred to above

Treatment At operation the aim was to "draw down the patella into the groove In 9 knees this was done by chiselling free the tibial tuberosity with the ligament and attaching it 1–2 cm distally in a new bed with a screw On 3 knees in two patients (10 and 12 years of age)

a raphe was made on the ligament in order not to injure the epiphyseal plate

All joints were opened by a medial incision and *inspected The cartilage* the ligaments and the menisci were normal In 4 cases a slight effusion and swelling of the synovial membrane was noticed

Mean age at operation was 21 years (39–10)

After surgery the knee was put in a plaster cylinder for 3 weeks *The only complication* was *temporary* peroneal nerve palsy in one patient with diabetes (plaster pressure?)

Result In 11 knees, the end result was considered excellent the patients were *subjectively trouble free range of movement* was *normal* and muscle strength 5 (according to the 0–5 grading) Mean observation time was 4 years 6 months (7–1 years) The end result was in all cases achieved within a year the last degrees of full flexion were the most difficult to obtain

One knee was a *failure (case no 2, Table 1)* in spite of good position of the patella after surgery (checked by X ray) the symptoms remained and 2 years later the patient had 3 dislocations of the patella in 2 months She was operated on *ad modum Krogius (1904)* with good result

A few cases call for a more detailed description

Knee No 3 Girl 12 years of age Complained of an ache and a feeling of discomfort in the right knee which was always flexed at an angle of *5–10* degres She was examined under anaesthesia and the knee could be straightened completely It was found that the patella slid laterally about 1 cm, and stayed there riding over the lateral *femoral condyle The patella maintained this position* when the knee was bent a few degrees and not until it was *flexed* a few degrees further did the patella slide into the groove with a slight click and it then articulated normally until the knee was again extended completely when the patella again slid laterally This was so unpleasant for the patient that *when conscious, she refused to straighten* the knee completely After operation (raphe of ligamentum patellae) she was trouble free (7 years observation time) No symptoms from the *left knee* but here *too* there is p a

Knee No 4 and 5 This patient was *considered* by teachers and school friends *to be* a *trifle strange because she always* walked with slightly bent knees

Knee No 7 and 8 This patient was an enthusiastic spectator at football matches but was always troubled by pronounced ache and feeling

of tiredness in the knees after he had been standing for 5–10 minutes He then discovered that he could stand more comfortably with his knees flexed about 20 degrees and supported against a lemonade box The patella was thus drawn down into the groove and obtained bony support and his symptoms then disappeared He was free from symptoms after bilateral operations

DISCUSSION AND SUMMARY

That patients with recurrent dislocation of the patella often have patella alta (p a) is known and if a patient with an obvious dislocation in the history visits the clinic the position of the patella in the vertical plane is investigated to see whether a p a is present The diagnosis must be made rontgenologically and clinically (Blumensaat s line the contour of the knee joint at 90 degrees flexion and possible abnormal mobility laterally)

Through the unphysiological articulation between the patella and the distal femur however p a can result in other symptoms than dislocation ache tiredness exudate feelings of instability and in some cases catching of the patella and it is essential to consider the diagnosis with these different symptoms even though there is no history of dislocation

The author describes 12 knee joints in 8 patients where the symptoms have been so pronounced that an operation was considered necessary The patella was drawn distally into the intercondylar groove of the femur by raphe of the patellar ligament (3 knees) or distal transfer of the tibial tuberosity (9 knees)

Results were excellent in 11 cases and the success of the operation is taken as proof of the symptoms having been caused by high standing patella

The author made the diagnosis p a in 18 other knees and believes this to be the explanation of the patients symptoms (which were the same as in the operation group) Operation however was refused (slight symptoms) or was postponed

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ACTA ORTHOPAEDICA SCANDINAVICA

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Department of Orthopaedic Surgery (Heads J Falkenberg and E. B Olesen)
Central Hospital Næstved Denmark

CONGENITAL RADIO ULNAR SYNOSTOSIS

Report of 37 Cases

O Hart Hansen & N Ortved Andersen

Received 26 I 69

Congenital synostosis of the proximal ends of the radius and ulna is a rare malformation which often completely prevents pronation and supination of the forearm According to Wilkie (1914) the first case was described in 1793 by Sandifort in his *Museum Anatomicus* Perusing the literature up to 1964 Jeants found that so far a total of about 990 cases had been published During the period 1912–1967 a total of 194 patients with congenital malformations of the forearm were seen in the Orthopaedic Clinic in Munich Among these patients Albrecht (1967) found 7 with congenital radio ulnar synostosis

PRESENT MATERIAL

At a brief inter [illegible] patient with congenital proximal radio ulnar synostosis Peru [illegible] f th [illegible] le from 10 orthopaedic departments in Denmark revealed that [illegible] th 10 [illegible] r period 19 8–1968 this deformity had been diagnosed in 37 c [illegible] Th [illegible] e enly distributed over the country

RESULTS

Of th [illegible] patients 16 were females and 21 males In 28 cases the diagnosis had been made between the ages of 1 and 12 years and the remaining [illegible] patients were between 16 and 52 years Twenty-eight were referred [illegible] orthopaedic out patient department because members of the family had noticed reduced mobility of the forearm 2 were detected by [illegible] when examined for something else and 7 applied because of difficulties in performing their work

In [illegible] instances there was a familial predisposition All the familial [illegible] re bilateral transmitted through the paternal line In one of

the families the disease was present in the patient s paternal grand mother father and 3 paternal uncles

In 12 cases the anomaly was right sided in 6 left sided and in 19 bilateral

Several authors have classified the radio ulnar synostoses into two types In one type (the so called primary radio ulnar synostosis) the proximal end of the radius is imperfectly formed and is fused to the ulna for a length of 3–6 cm The normal contour of the radial head is completely obliterated and the radial shaft is distinctly forward arched longer and considerably stouter than the ulna which is more slender than usual In the other type synostosis is less marked and the radial head is dislocated forward or backward In the present material 27 cases were of the former type and 6 of the latter In four of the bilateral cases type I was found on one side and type II on the other

In all the patients the hand was more or less pronated In 12 it was fixed in maximum pronation In type I cases pronation and supination were practically abolished while in type II mobility was from a few degrees up to approximately half the normal range About one third of the patients had an extension defect of 10–30 in the elbow whereas the others had free mobility in this joint

No patient showed congenital malformations other than the synostosis

It is apparent from the case records that in a number of the cases there had been doubt as to whether the patients were to be advised to have operation of the synostoses Several of the children were followed with a view to possible operation when they had grown up Only two of the patients underwent operation These two cases as well as a typical case history will be reported below

CASE REPORTS

1 A 16 year old girl was referred to an out patient department because of reduced mobility of the right forearm The complaints were mild manifesting themselves mainly in difficulty of writing and sewing The symptoms had been present from birth There were no similar cases in the family

On physical examination the right forearm was found to be fixed in a position of extreme pronation Pronation supination was completely abolished Otherwise mobility of the elbow joint and wrist was free On the left there was also a tendency to pronation of the forearm On this side the range of pronation supination was about half the normal X rays (cf Figure 1) showed on the right a 4½ cm area of total synostosis between the proximal end of the radius and ulna The radius was very stout and distinctly forward arched On the left there was a very

small synostosis combined with upward and backward dislocation of the radial head

The patient was advised against operation



Figure 1 Congenital radio-ulnar synostosis in a girl aged 16 years Right arm

2 A 16 year old girl with bilateral proximal radio ulnar synostosis was referred because of abolished rotation in both forearms Partial resection of the left radius was performed removing 2 cm of the bone just below the synostosis In spite of intensive training active rotation of the forearm was not attained At X ray follow up 18 months later there was again osseous contact between the resected bone ends Supination pronation was still abolished Subjective complaints had been somewhat reduced as the hand previously in maximum pronation was now fixed in 30 pronation The patient was not interested in an operation on the right arm

3 A 16 year old boy was admitted with right sided congenital proximal radio ulnar synostosis The hand was in maximum pronation and supination could not be performed As the patient was going to be an artisan he needed better function of the hand Osteotomy was done at the junction of the distal two thirds and the proximal one third of the radius The hand was fixed in 30 pronation During the postoperative course the function of the radial nerve was affected but this improved considerably after myotensor therapy Three months after the operation the osteotomy had healed Pronation supination was still abolished and the subjective complaints were practically unchanged

DISCUSSION

According to the present study congenital radio-ulnar synostosis is somewhat more common than would be expected according to previous investigations

The symptoms in these cases consist of reduced or entirely abolished

supination and pronation of the forearm *Apparently the hand is always fixed in pronation* This is fortunate since the patients would be much worse off with the hand in supination The restriction of mobility may to some extent be compensated for by movements of the shoulder In unilateral cases the affected forearm is often thinner and somewhat shorter than the good one The explanation why the patients seldom complain of the restricted mobility is perhaps habit as they have never known free use of the forearms

From the literature it is apparent that the condition is bilateral in more than 80 per cent of the cases In our series close to 50 per cent were bilateral The malformation appears to be equally common in both sexes In a few cases there is a family history of synostosis (Fraser 1966 Mercer 1950 Wallace 1914) Among our patients about 13 per cent had a familial predisposition These cases apparently always bilateral were transmitted mainly through the paternal family

Radio ulnar synostosis has been described in Klinefelter s syndrome with an XXXY chromosomal pattern Among 6 patients with radio ulnar synostosis Cleveland et al (1969) found two to be of an XXY karyotype The relationship of the bony abnormality to the presence of an extra X chromosome was not clear A chromosomal study was not performed on the present material

As already mentioned many authors have divided the synostoses into 2 separate types In 4 of our cases the condition was type I on one side and type II on the other It seems reasonable to assume therefore that there is not a question of 2 separate varieties of malformation but of a difference in degree

It is well known that synostosis between the radius and ulna may arise as a consequence of fractures It is extremely rare for this acquired form to be mistaken on the X ray film for the congenital form Fielding (1964) has reported the case of an 11 year old boy in whom traumatic epiphysiolysis of the radial head was followed by radio ulnar synostosis of the same configuration as the congenital variety *He was* unable to find reports of similar cases in the literature Congenital and traumatic dislocation of the radial head in children has been reported several times Schubert (1965) published a case arising from a difficult breech delivery The dislocation did not lead to radio ulnar synostosis as it was recognized immediately and treated by reduction and fixation in plaster It cannot be ruled out that some of the unilateral synostoses are *not congenital* but due to injuries sustained at or shortly after birth

It has been reported that patients with congenital radio ulnar synostosis frequently have other malformations too e g dislocation of the hip anomalies of the knee joint club-foot flat feet Madelung s deformity syndactyly and polydactyly (Freyer 1966 Mercer 1950 Wilkie 1914) Among our 37 patients 2 had Scheuermann s kyphosis and 2 were intellectually impaired but there were no cases of other malformations

Operations and autopsies have revealed apart from the osseous changes atrophy and fibrosis of the supinator muscles as well as of the pronator teres and pronator quadratus The interosseous membrane is thickened and very tight (Hohmann 1962 Mercer 1950 Wilkie 1914)

The results of surgical treatment have often been extremely unsatisfactory (Bier et al 1958 Jeanty 1964 Mercer 1950 Wilkie 1914) Even after radical resection of the synostosis with interposition of fat muscle or a piece of plexiglass and after passive pronation and supination of the forearm has been rendered completely free considerable or total restriction of movement usually recurs (Bier et al 1958) Hohmann (1962) published the case of a 6-year old boy whom he had treated by cutting the shaft of the radius in the middle and turning the forearm from maximum pronation to an intermediate position Thereby he obtained considerable improvement of hand function Kelikian & Doumanian (1957) designed a stainless steel swivel which they inserted into the medullary cavity after resecting a piece of the radius so that the bone could rotate on the cylindrical prosthesis This prosthesis has been used successfully in 4 cases of traumatic radio-ulnar synostosis Although they had not tried it they believed that the swivel was well suited for the congenital cases too However the result is not likely to be favourable as the congenital synostoses consist not only in osseous changes but also in changes of the muscles and interosseous membrane Therefore even though free passive pronation supination is obtained active mobility will not be significantly improved

On the basis of the literature and the above case histories (2 and 3) it may be concluded that it is advisable to refrain from operation in most cases of congenital proximal radio ulnar synostoses If in a rare case the complaints are so severe that an intervention is required it seems reasonable to restrict it to osteotomy on the forearm placing the hand in an optimum position for function

supination and pronation of the forearm Apparently the hand is always fixed in pronation This is fortunate since the patients would be much worse off with the hand in supination The restriction of mobility may to some extent be compensated for by movements of the shoulder In unilateral cases the affected forearm is often thinner and somewhat shorter than the good one The explanation why the patients seldom complain of the restricted mobility is perhaps habit, as they have never known free use of the forearms

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Clinic for Orthopaedics and Traumatology University Central Hospital
Helsinki Finland

BONE CHANGES IN PARATHYROID ADENOMA

Report of a Case

Pentti Rokkanen & Heljo Julkunen

Received 1 iv 69

Primary hyperparathyroidism often called von Recklinghausen s di sease is caused by hyperplasia adenoma or carcinoma of the parathy roid gland The clinical symptoms are muscular weakness nausea polyuria and bone pains The disease can lead to renal colic owing to concrements in the urinary tract and to pathologic fractures owing to bone cysts and osteoporosis A parathyroid tumour containing clear wasserhelle cells or chief cells is a typical microscopic finding (Bern stein & Thorn 1966 Barnhart 1967)

Urinary phosphorus is increased serum phosphorus decreased and serum calcium increased in primary hyperparathyroidism According to more recent publications the calcium infusion test has less diagno stic value because urinary phosphorus may also be reduced in normal conditions and in cases of renal calculi (Horwith et al 1966) The hydroxyproline excretion is often elevated (Johnston et al 1966 Hor with et al 1966) Serum calcium is rarely decreased in the cortico steroid suppression test (Anderson et al 1954 Dent 1956) but such a case has been described (Hodges & Waterhouse 1967)

The authors had an opportunity to study bone changes in a case of parathyroid adenoma by oxytetracycline bone labelling and microradio graphy before and after removal of the adenoma

CASE REPORT

Patient H T 110418 a 45 year old woman clerk. She had had asthmatic symptoms 16 and 30 ye rs ago and hepatitis 20 ears ago In July 1965 after a sl ght trauma f the right han l there was on et of pain and swelling in the fifth metacarpal area The p tient ought tre tment because of the cyst and pathologic fracture of the fifth m tacarp l At oper tion oftened bone was found and a light red tumour

SUMMARY

In 10 Danish departments of orthopaedic surgery 37 cases of congenital radio ulnar synostosis were diagnosed during the 10 year period 1958–1968 Of these patients 16 were females and 21 males 12 cases were right-sided 6 left-sided and 19 bilateral Five of the patients had a family history of radio ulnar synostosis These cases all bilateral had been transmitted through the paternal family In the literature the synostoses are divided into 2 types In 4 of the present cases we found type I on one side and type II on the other Very probably therefore there is not a question of two different forms of malformation but of a difference in degree

Two of the patients had undergone operation without obtaining any essential improvement of their condition It is concluded that congenital radio ulnar synostosis should in most cases not be treated surgically

ACKNOWLEDGEMENTS

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Urinary phosphorus is increased serum phosphorus *decreased and* serum calcium increased in primary hyperparathyroidism According to more recent publications the calcium infusion test has less diagnostic value because urinary phosphorus may also be reduced in normal conditions and in cases of renal calculi (Horwith *et al* 1966) The hydroxyproline excretion is often elevated (Johnston et al 1966 Horwith et al 1966) Serum calcium is rarely decreased in the corticosteroid suppression test (Anderson et al 1954 Dent 1956) but such a case has been described (Hodges & Waterhouse 1967)

The authors had an opportunity to study bone changes in a case of parathyroid adenoma by oxytetracycline bone labelling and microradiography before and after removal of the adenoma

CASE REPORT

Patient H T 110418 a 48 year old woman clerk. She had had asthmatic symptoms 16 and 30 ye rs ago and hepatitis 20 years *ago In July 196* after a slight trauma of the r ght hand there was onset of pa n and swelling *in the fifth* metacarpal area The p tient ought treatment because of the cyst and pathologic fracture of the fifth metacarpal At operation softened bone was found and a *light* red tumour

was removed by metacarpal resection Bone grafting from the iliac crest was performed The histologic picture resembled a giant cell tumour

At follow up the bone graft was united but bone cysts were seen in the third metacarpal and the first phalanx of fourth finger (Figure 1) The patient was admitted in July 1965 for further study Her general condition was good She had a node attached to the left lobe of the thyroid gland Chest radiograph and ECG were normal Other radiographic findings in bones were salt and pepper changes in the skull and osteoporosis in the spine an osteoporotic compression fracture in the first lumbar vertebra and bone cysts on the left humerus and fibula No renal calculi were visible Laboratory values Blood picture and ESR were normal Serum proteins were 5.4–5.8 per cent sodium 138–144 mEq/l potassium 4.1–4.6 mEq/l creatinine 1.9–2.1–0.8–1.0 mg% calcium 13 mg% = 6.5 mEq/l phosphorus 1.4 mg% and alkaline phosphatases 11.0 Bessey Lowry units Urinary sediment was normal There were no traces of proteins glucose or Bence Jones proteins in urine Excretion of calcium in the urine was 0.18 g/24 h and of phosphorus 0.87 g/24 h The *Kveim* test was negative

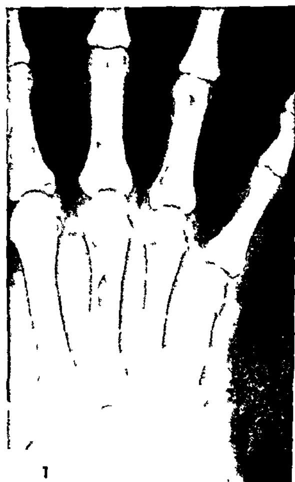


Figure 1 Bone cysts in the third metacarpal and in the first phalanx of the fourth finger in a case of parathyroid adenoma A large cyst of the fifth metacarpal was earlier resected and bone grafting performed

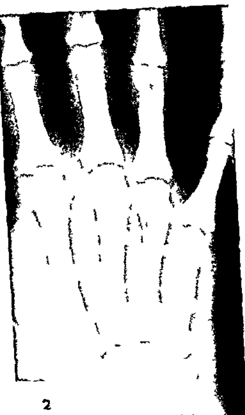


Figure 2 Bone cysts have disappeared one year after removal of parathyroid adenoma

A corti steriod supp es ion test using delt cortisone 40 mg/day during 10 days was done At fir t the serum calcium valu was 13 mg% on the fourth day 13 4 mg% and on the ninth day 13 0 mg%

Before the operation 0 5 g of tetracyclin was given daily on two days for the bone fluor scence examination At operat on two tumours of the size of a plum were found one in the thyroid and the ther behind it in separate capsules The tumours were removed and frozen sl es of the parathyroid tum ur wer made The histologic examination revealed well vascularized tumour tissue ontaining clear wasse helle cells On the fir t postoperative day the s rum calcium was reduced to 9 8 mg% and on the sixth day to 6 5 mg% The patient was treated with intramu cular calcium gluconate and d hydrotachysterole (A T 10 Baye fifteen drops × 3/day) No tetanic convulsions occurred The serum calcium was followed nd dihydrota hysterole was withdraw n after half a ye r and later also the calcium tablets

The patient as admitted to hospital in July 1967 Most of th bon changes had di appe r d (Figure 2) serum calcium w s 9 4 9 5 mg% pho phorus 2 6 4 0 mg% U in ry exc eti n of calc um was 0 48 g/24 h phosphorus 0 43 g/24 h and hydroxy

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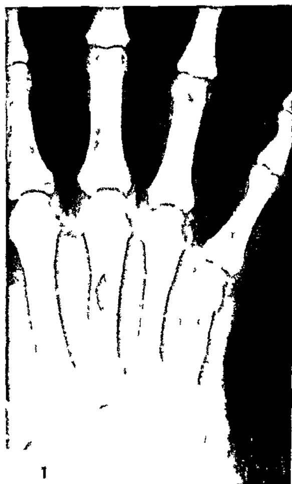


Figure 1 Bone cysts in the third metacarpal and in the first phalanx of the fourth finger in a case of parathyroid adenoma A large cyst of the fifth metacarpal was earlier resected and bone grafting performed


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5


6

Figure 3. Microradiograph showing eroded and fragmented trabeculae of the iliac crest with low density. × 100

Figure 4. Microradiograph of iliac crest bone one year after removal of parathyroid adenoma. The margins of trabeculae are clearer, the density is better. Renegerative new mineralized areas are seen in the cancellous spaces. × 100

Figure 5. Microradiograph of an osteon with wide osteroid before removal of adenoma. × 250

Figure 6. Microradiograph of a narrower osteoid in the osteon one year after removal of adenoma. × 250

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proline 14.2 mg/m²/24 h. The patient was given tetracycline before a repeated biopsy of iliac crest bone.

To summarize the case report, the authors describe a case of primary hyperparathyroidism admitted to hospital because of a pathologic fracture. The diagnosis was verified by the clinical picture as well as by elevated serum calcium, positive corticosteroid suppression test, and histologic features of parathyroid adenoma. Iliac crest bone biopsies were taken for study of bone changes before and after removal of the adenoma.

MICRORADIOGRAPHIC AND TETRACYCLINE FLUORESCENCE EXAMINATIONS

The bone samples were hardened in methylmetacrylate and ground to a thickness of 100 μ. The fluorescence examination was performed with a Leitz microscope. At microradiography the following values were used: 15 mA, 24 kV, 5 min, FSD 15 cm.

In the bone samples taken before removal of the parathyroid adenoma, tetracycline-fluorescence was seen in the margins of trabeculae. In the samples taken one year after operation there was obvious fluorescence in large cancellous areas and also in the cancellous spaces.

In the first microradiographs (Figures 3 and 5) a thin bone network of a low bone density were seen. There was clear fragmentation and the margins of the trabeculae were eroded. In some places the osteons were indistinct.

The second microradiographs taken one year after operation (Figures 4 and 6) showed a less fragmented bone network and less unclear osteons. The trabecular margins were clearer, but also trabeculae with eroded margins were present. In the cancellous spaces new mineralized regenerative areas were visible.

crest biopsy material were performed before and after removal of the parathyroid adenoma Visible tetracycline fluorescence was found before and after removal of the tumour In microradiographs fragmented trabeculae eroded margins of a low density and rich osteoid were seen One year after removal of the adenoma there were less fragmented trabeculae better density less abundant osteoid and regenerative bone areas

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DISCUSSION

In a case of primary hyperparathyroidism studied with tetracycline fluorescence using tetracycline during 7 days before biopsy (Hupe & Horn 1965) clear ossification was found in the margins of the Haversian canals and endosteal bone In the present study a more obvious uptake of tetracycline seen both at the trabecular margins and in the cancellous spaces one year after the operation than before it indicating a more active regenerative process

In the radiocalcium study of Dymling (1965) increased accretion rate and its decrease after removal of parathyroid tumour was found Another study (Caniggia et al 1966) shows elevated values of the calcium miscible pool Ca turnover rate and accretion and resorption rates Histologically there was irregularity of the surfaces of the trabeculae and sparse and narrow osteoid seams Two weeks after removal of a parathyroid adenoma, histological examination showed broad trabeculae and a large osteoid which was normalized within 45 weeks At the same time the elevated values of the Ca miscible pool Ca turnover rate accretion and resorption had decreased Intestinal hyperabsorption decreased already within 2 weeks Microradiography (Bovet & Towsey 1966) revealed an increase in width of osteoid tissue as compared to normal speaking against the finding by Caniggia et al (1966) In the present study regenerative processes were observed both by microradiography and by ordinary X-ray one year after operation

The present case speaks for the concept that in primary hyperparathyroidism the bone changes are similar to those in osteomalacia poor mineralization and rich osteoid and after a one year observation period changes indicating a still active regenerative process The new bone formation in cancellous spaces seen by microradiography one year after removal of the adenoma is an interesting phenomenon It shows that healing of the bone continues although bone cysts and osteoporosis have disappeared

Primary hyperparathyroidism is an important although rare disease Poor mineralization or bone cysts give reason for the estimation of the serum calcium and phosphorus and for further studies among fracture patients

SUMMARY

A case of parathyroid adenoma with bone cysts was described Microradiographic and tetracycline fluorescence examinations of the iliac

a living animal which would record the bone s behaviour in its normal biological and mechanical environment

To gain any relevant understanding of the behaviour of bone as a skeletal unit it is essential that it be studied under these conditions The scrutiny of fracture types or their experimental production (Evans 1957 Hirsch 1954) yields information concerning the forces within the living system at the instant of failure but these circumstances are patently not normal To obtain information regarding the response of various parts of the skeleton to the forces they normally encounter it was decided to implant gauges into the living animal and subsequently study their behaviour during normal locomotion

The medial aspect of the tibial shaft was a suitable gauge site for preliminary work since it is readily accessible and has no muscles attaching to it It could also be expected to have a characteristic strain pattern during locomotion closely related to the movements of the hind limb

Sheep were used as experimental animals as they are a convenient size for handling anaesthesia presents no special problems and they do not require any complicated husbandry Once trained they will readily walk on a moving platform long trailing wires and a large work space are thus not necessary and filming is made much easier

METHOD

In the initial experiments polyester backed wire strain gauges with a gauge factor of 1 9 were used in a D C bridge circuit (In tension or compression strain is the change of length per unit length $\delta L/L$. The *gauge factor is the ratio between change* in electrical resistance and change in length gauge factor = $\delta R/R / \delta L/L$.) Al though results were obtained with this *apparatus* it was plagued with many problems which were eliminated by transferring to an A C system and semiconductor strain g uges whose gauge factor was fifty times as great (100) These consisted of a U shaped semiconductor strain *sensiti e element* encapsulated in an epoxy bonded glass fibre c rrier

The gauge wires from each arm of the U were soldered to PTFE (poly tetra fluor ethylene) covered leads of sil er plated copper wire The soldered joint was pro tected by a sl ghtly flexible epoxy resin coating (Prepot No 1 Fleming Services Cambridge) exp nded laterally to *form two* flanges just proximal to the gauge Another flange was moulded round the leads 1 cm proximal to the first. At their ther ends the leads were connected to *a multipin* socket embedded in an epoxy esin casting In this way all connections were protected from their environment

Several gauges were implanted at *a time* One of these instead of being fixed to the til a was bonded to a piece of stainless steel and placed near the others Al though und r similar cond tions it would not be attached to any stress bearing

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Department of Veterinary Anatomy University of Bristol U K

BONE STRAIN IN THE TIBIA DURING NORMAL QUADRUPEDAL LOCOMOTION

L E LANYON & R N SMITH

Received 1 ix 69

Many studies have been made on the mechanical response of bone and bones to forces applied to them These have frequently involved the removal of a small sample from the body its reduction to a convenient shape both for mathematical analysis and for handling in a test machine and its subjection to various loads (Ascenzi Bonucci & Checcucci 1966 Cooke 1955 Coolbaugh 1952 Currey 1959 Dempster & Coleman 1961 Evans & Lebow 1952 Evans & Bang 1966 Forssblad 1959 Sedlin & Hirsch 1966 Semb 1966 Smith & Walmsley 1959 Weaver & Chalmers 1966)

Other investigations have been carried out using whole bones either *in situ* or removed from the cadaver and denuded of their surrounding tissues (Evans 1953 1957 Evans & Lissner 1948 Evans Lissner & Patrick 1962, Evans Lissner & Pedersen 1948 Gurdjian & Lissner 1944 1945, Hirsch & Brodetti 1956 Hirsch & Evans 1965 Kalen 1961 Lissner 1964 Lissner & Roberts 1966 Martz 1956 Stevens & Ray 1962)

These investigations involved stressing the bone artificially and studying its response in various ways Many of these workers used strain gauges either bonded to a test piece (Forssblad 1959 Frankel & Burstein 1964) to the isolated bone (Gurdjian & Lissner 1944 Hirsch & Brodetti 1956 Hirsch & Evans 1965) or to the bone *in situ* (Evans et al 1962 Lissner 1964 Lissner & Roberts 1966) Evans (1953) mentions the use of strain gauges as a possible method of measuring strain *in vivo* and cites an experiment the results of which seem to be unpublished in which he Coolbaugh and Lebow bonded a gauge to the tibia of a dog Lissner bonded gauges to the vertebral bodies of dogs and human cadavers during ejection seat trials Kilpatrick (1967) mentions some unpublished experiments where gauges were bonded to living bone But apart from a short preliminary report (Lanyon & Smith 1969) no results appear in the literature from gauges implanted into

a living animal which would record the bone's behaviour in its normal biological and mechanical environment.

To gain any relevant understanding of the behaviour of bone as a skeletal unit it is essential that it be studied under these conditions. The scrutiny of fracture types or their experimental production (Evans 1957, Hirsch 1964) yields information concerning the forces within the living system at the instant of failure but these circumstances are patently not normal. To obtain information regarding the response of various parts of the skeleton to the forces they normally encounter it was decided to implant gauges into the living animal and subsequently study their behaviour during normal locomotion.

The medial aspect of the tibial shaft was a suitable gauge site for preliminary work since it is readily accessible and has no muscles attaching to it. It could also be expected to have a characteristic strain pattern during locomotion closely related to the movements of the hind limb.

Sheep were used as experimental animals as they are a convenient size for handling, anaesthesia presents no special problems and they do not require any complicated husbandry. Once trained they will readily walk on a moving platform; long trailing wires and a large work space are thus not necessary and filming is made much easier.

METHOD

In the initial experiments polyester backed wire strain gauges with a gauge factor of 1.9 were used in a D.C. *bridge circuit*. (*In tension or compression strain is the change of length per unit length* $\delta L/L$. The gauge factor is the ratio between change in electrical resistance and change in length, gauge factor $= \delta R/R / \delta L/L$.) Although results were obtained with this apparatus it was plagued with many problems which were eliminated by transferring to an A.C. system and semiconductor strain gauges whose gauge factor was fifty times as great (100). These consisted of a U shaped semiconductor strain sensitive element encapsulated in an epoxy bonded glass fibre carrier.

The gauge wires from each arm of the U were soldered to PTFE (poly tetra fluor ethylene) covered leads of silver plated copper wire. The soldered joint was protected by a slightly flexible epoxy resin coating (Preput No. 1, Fleming Services, Cambridge) expanded laterally to form two flanges just proximal to the gauge. Another flange was moulded round the leads 1 cm proximal to the first. At their other end the leads were connected to a multipin socket embedded in an epoxy resin casting. In this way all connections were protected from their environment.

Several gauges were implanted at a time. One of these instead of being fixed to the tibia was bonded to a piece of stainless steel and placed near the others. Although under similar conditions it would not be attached to any stress bearing

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structure From the behaviour of this dummy we hoped to be aware of any conditions other than strain which cause an alteration in gauge resistance

Each unit consisting of active and dummy gauges leads and multipin socket was disinfected by a low temperature steam and formaldehyde process (Alder et al 1966)

The sheep were operated on under general (Halothane) anaesthesia A small incision was made in the flank to receive the epoxy embedded multipin socket and another longer one to expose the medial surface of the tibial shaft The gauges were fed along a polythene tube connecting the two incisions which when removed left the leads in place

The tibial periosteum was reflected and the gauge site after being carefully wiped was treated with surface activator (X83/272 Ciba (A R L) Ltd Cambridge) Once this had evaporated the adhesive (Isobutyl 2 cyanoacrylate monomer Ethicon Ltd) was applied to the undersurface of both gauge and flanges and these were speedily pressed in position The monomer rapidly polymerized if the gauge site had been properly prepared Each active gauge was treated in the same manner The periosteum was sutured and the dummy gauge positioned nearby The wound was then closed

Healing was good the animals although lame for twenty four hours and favouring that limb for a few days walked perfectly soundly within a week

A bony outgrowth and dense fibrous tissue reaction developed where the periosteum had been reflected However this did not seem painful and served to hold the leads firmly in place

Once walking soundly the sheep which had been previously trained was put on the moving platform A multipin plug was attached to the socket in the animal's flank so connecting the implanted gauges to transducer meters (C 52 Boulton Paul Aircraft Ltd Wolverhampton) Each gauge formed one arm of a bridge circuit any change in its resistance produced an out of balance signal across the bridge The output from the transducer meters resulting from this signal was fed via suitable filters to the galvanometers of an ultra violet recorder Thus the strain pattern from each gauge was instantly recorded as the animal walked

In addition to the gauge trace signals were recorded from a small variable inductance accelerometer strapped to the dorsal aspect of the middle phalanges From the shape of the trace that this instrument produced we could determine the phase of the stride To ensure that the accelerometer was providing a reliable indication of limb movement and to allow for more detailed analysis a slow motion film (64 frames per second) was also taken

Paper trace and film were synchronized with the aid of a large clock face which was included in the photographic field An eccentric cam on the hand shaft triggered a micro switch once every revolution causing a bulb on the clock face to flash and a spike to appear on one of the recorder channels By this means any incident on the film could be accurately timed on the traces and vice versa

RESULTS

Varying numbers of semiconductor and wire resistance strain gauges were implanted during ten operations

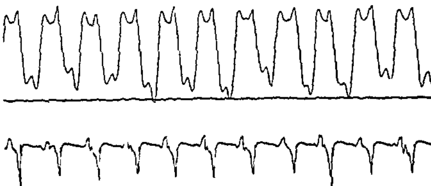


Figure 1 The trace of an active gauge bonded to the medial aspect of the right tibia of a walking animal and a dummy bonded to a piece of stainless steel and positioned nearby Below these is the tra e from the accelerometer strapped to the right hind l mb

F gure 2 Th tra e from the same gaug s taken during trotting The accelerometer tra e is also shou n

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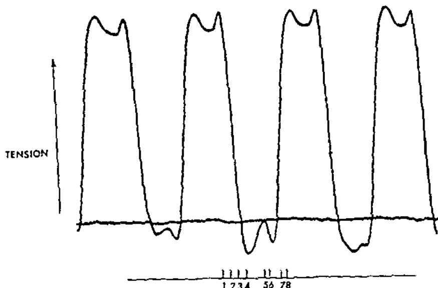


Figure 3 Analysis of a trace obtained during walking The numbered instants correspond to those in the text and to the numbered illustrations in Figure 4

upon the tibia during the consequent diagonal support phase was only halted when the right fore foot was placed to the ground (Figure 3 point 4)

This transitory triangular support phase was terminated when the left foot was lifted (Figure 3 point 5) leaving a right unilateral support The resulting transfer of weight to the test limb coincided with a reimposition of compression By now this limb was nearing the end of its stride The contralateral hind limb was placed on the ground (Figure 3 point 6) allowing a compressional release which continued during the initial part of the swing phase (Figure 3 point 8) and appeared to overshoot before returning to the level immediately preceding the foot being replaced on the ground

A trot consists of alternate diagonal support phases With the absence of any complicated transference of weight during triangular and unilateral support phases there is no inflexion at the base of the compressional period which occurs on the walking traces The overshoot following the release of compression during the swing phase is similar to but more exaggerated than that which occurs during walking

The total change in strain (trace height) occurring during at least 10 consecutive strides was measured on the daily recordings The overall

The traces shown (Figures 1 and 2) are typical and were obtained from one animal during walking and trotting on the moving platform Traces from both 'active' and 'dummy' gauges are shown the 'active' gauge was bonded to the cranio medial aspect of the midshaft of the right tibia The 'dummy' gauge was positioned nearby Whilst the 'dummy' trace shows no response to the animal's movement the 'active' trace conforms to a regular pattern related to the movement of the limb as indicated by the trace from the accelerometer strapped to it

This was a constant and expected finding during these experiments any pattern present in the 'dummy' trace produced by a gauge supposedly not subjected to any change in strain would have been an artefact and would have undermined confidence in the reliability of the 'active' traces

Traces were reproducible daily over a period of two or three weeks after which the animals were killed Many similarities existed between strain patterns from different sheep naturally differences existed also Although all gauges were orientated along the long axis of the bone no effort was made to use exactly the same gauge site In any case there was considerable individual variation in the style of gait shown by each animal

In some cases results became erratic and were no longer considered reliable If this occured the experiment was terminated The commonest cause of failure was fatigue fracture of the leads usually near the femoro tibial joint where they were subjected to continual bending Damage to the insulation failure of soldered joints and deterioration of the bond caused failure in some cases

Once removed from the cadaver all tibiae were placed in a test apparatus where a rhythmical bending force could be applied to the midshaft both ends of the bone being supported Results obtained *in vivo* were only considered reliable if the gauge traces so obtained conformed to the expected sine curve pattern thus producing qualitative evidence that the gauges were still accurately responding to bone strain

From a frame by frame analysis of the slow motion film it was shown that the trace conformation was related not only to movements of the test limb but also to those of the other limbs as weight was distributed amongst them This is shown in Figures 3 and 4 During walking when the right hind foot (test limb) was seen to contact the ground (Figure 3 point 1) there was an immediate tensional rise on the trace which reached its peak just before the sole of the left hind foot was seen to lift (Figure 3 point 2) The compression imposed

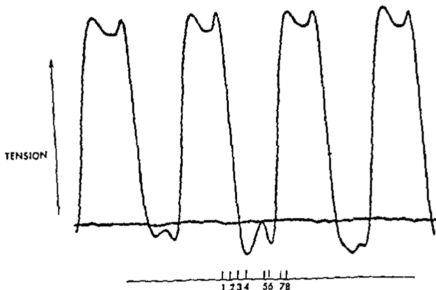


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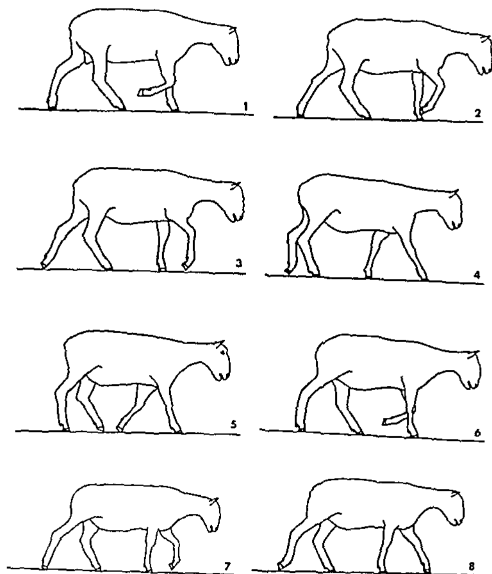


Figure 4 (1) Right hind foot (test limb) contacts the ground triangular support phase Small initial tensional phase on the trace (2) Sole of left hind foot lifts Period of sustained compression begins (3) Left hind limb enters its swing phase Compression continued (4) Right fore foot placed on the ground triangular support phase Some release in the compression (5) Left fore foot leaves the ground right unilateral support phase Compression reimposed (6) Left hind foot placed on the ground triangular support phase Period of sustained compressional release begins (7) Sole of right hind foot lifts Compressional release continues (8) Right hind limb enters its swing phase Compressional release continues and overshoots before the foot again contacts the ground

average from the 4th–28th day postoperatively is shown in Table 1. The reasonably large standard deviation for this figure is related to the changing conditions over the experimental period. Although appearing to walk soundly by the 4th day it is unlikely that full weight was placed on the limb so soon. Inevitably the animal gained confidence and walked more easily as the experiment progressed. The daily trace height increased until the 14th day and then gradually diminished. The average figure for five day periods at the beginning, in the middle and at the end of the experiment are shown. The decrease in value from 14th–28th day is probably associated with deterioration in the bone gauge bond.

Table 1. Sheep S 11

		Mean trace height microstrain	Standard deviation
Walking			
Per day overall	4th–28th day inclusive	262	40.3
Per 5-day period	4th– 8th day	238	12.3
	14th–18th day	317	13.9
	24th–28th day	[illegible]1	23.3
Trotting			
Per day overall	12th–28th day	305	51.3
Per 5 day period	14th–18th day	353	17.9
	24th–28th day	255	28.6

1 microstrain is 1×10^{-6} cm/cm

DISCUSSION

The significance of findings from one gauge in one position can only be of limited value in determining the stress patterns existing in the bone. The strain sensitive elements were only 2 mm by 0.5 mm and could only respond to the strain in the small area of bone to which they were bonded. For a complete analysis theoretical predictions of the strain pattern that would be expected should be made and these verified by experimental means. This would entail many gauges being bonded to selected sites on any one bone.

Until some knowledge is available concerning the working loads of various skeletal components and their response to them, design for their artificial replacements can only be based on surmise assisted by

theoretical computations of forces due to body weight muscle pull etc which of necessity so simplify the picture as to be of doubtful value unless supported experimentally The large and variable forces exerted by muscles on small areas of bone must produce an extremely complicated stress pattern

Although in this report bone strain has been related to weight bearing alone the greatest potential source is muscular The massive local deformation that culminates in fracture is in many cases the result of uncoordinated muscular action

Confidence in the experimental method and realization of its limitations are essential The existence in these experiments of constant strain patterns from day to day with similarities between animals is encouraging From the qualitative experiment described on the isolated tibia we know that the gauges do respond to bone strain However not yet having any quantitative means of verification, we were greatly concerned that changes in bone strain might not be the only stimulus Great care was taken in the use of two flanges, each bonded firmly to the bone to eliminate any effect of the leads pulling on the gauge and producing false indications of strain If this lead pull occurred one would expect large signals during the time that the leg is undergoing its most violent movement i e the swing phase In our experiments no great change of strain was indicated during this phase

If it is assumed that the only variable producing a signal is strain in the bone there is still the possibility that the magnitude of strain indicated is far less than actually occurs If the bond is not transmitting 100 per cent of the strain then the gauge cannot respond to it Even if the strain values in different experiments seem to agree this may only indicate the maximum efficiency of bonding possible and not actual bone strain To test the efficiency of the bond in this respect it is necessary to develop a quantitative method of calibration the gauge must be removed with the piece of bone to which it is bonded and strained to a known extent Difficulties arise in machining the piece of bone and not disturbing the attached gauge calibration and test would not be under identical conditions one *in vivo* and one *in vitro*, and even with a machined test piece computation of the actual strain in the gauge area may be inaccurate

Although much confirmatory work has yet to be done we believe that this approach will yield valuable basic information concerning the response of the skeleton to its mechanical environment which has not been available using less direct techniques

SUMMARY

A method has been reported which enables *in vivo* recordings of bone strain to be made in the walking animal

Semiconductor strain gauges have been used on the tibia of sheep to develop this technique and the incidental results showing the strain pattern from one gauge on the medial surface of the midshaft are illustrated

ACKNOWLEDGEMENTS

We are most grateful to the Department of Veterinary Surgery under Professor Messervy and especially to Dr Barbara Weaver for her great help and cooperation We thank Miss Mary Kear for her assistance during the experiment.

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theoretical computations of forces due to body weight, muscle pull, etc., which of necessity so simplify the picture as to be of doubtful value unless supported experimentally. The large and variable forces exerted by muscles on small areas of bone must produce an extremely complicated stress pattern.

Although in this report bone strain has been related to weight bearing alone, the greatest potential source is muscular. The massive local deformation that culminates in fracture is in many cases the result of uncoordinated muscular action.

Confidence in the experimental method and realization of its limitations are essential. The existence in these experiments of constant strain patterns from day to day with similarities between animals is encouraging. From the qualitative experiment described on the isolated tibia, we know that the gauges do respond to bone strain. However, not yet having any quantitative means of verification, we were greatly concerned that changes in bone strain might not be the only stimulus. Great care was taken in the use of two flanges, each bonded firmly to the bone, to eliminate any effect of the leads pulling on the gauge and producing false indications of strain. If this lead pull occurred one would expect large signals during the time that the leg is undergoing its most violent movement, i.e. the swing phase. In our experiments no great change of strain was indicated during this phase.

If it is assumed that the only variable producing a signal is strain in the bone, there is still the possibility that the magnitude of strain indicated is far less than actually occurs. If the bond is not transmitting 100 per cent of the strain, then the gauge cannot respond to it. Even if the strain values in different experiments seem to agree, this may only indicate the maximum efficiency of bonding possible and not actual bone strain. To test the efficiency of the bond in this respect it is necessary to develop a quantitative method of calibration: the gauge must be removed with the piece of bone to which it is bonded and strained to a known extent. Difficulties arise in machining the piece of bone and not disturbing the attached gauge; calibration and test would not be under identical conditions, one *in vivo* and one *in vitro*, and even with a machined test piece computation of the actual strain in the gauge area may be inaccurate.

Although much confirmatory work has yet to be done, we believe that this approach will yield valuable basic information concerning the response of the skeleton to its mechanical environment which has not been available using less direct techniques.

SUMMARY

A method has been reported which enables *in vivo* recordings of bone strain to be made in the walking animal

Semiconductor strain gauges have been used on the tibia of sheep to develop this technique and the incidental results showing the strain pattern from one gauge on the medial surface of the midshaft are illustrated

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Although in this report bone strain has been related to weight bearing alone the *greatest potential source is muscular The massive local deformation that culminates in fracture is in many cases the result of uncoordinated muscular action*

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CHANGES IN THE MUSCLE AND SKIN BLOOD FLOW FOLLOWING LOWER LEG FRACTURE IN MAN

EVA KELLEROVÁ, WOLFRAM DELIUS, SVEN OLERUD & GUNNAR STRÖM

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It is clinically well known that after skeletal fracture in the human lower leg or foot, local oedema may persist for a considerable period of time. The question arises whether a change in local blood circulation or a change in capillary permeability and lymph damage is the reason for the oedema.

Several authors using different techniques have shown on animals that following an experimental fracture or immobilization of an extremity the vascular volume and blood flow in muscles of the impaired extremity are increased at least relatively (Hulth & Olerud 1960, 1961, Imig et al. 1963, Lexer 1904, Ray et al. 1967, Rhinelander et al. 1968, Semb 1966, Stulcová & Hudlicka 1967, Wray 1964, Wray & Lynch 1959). This has been made evident not only by measurements of blood flow but also anatomically, both for muscle and bone tissues.

Apart from clinical observations following direct vascular injury (Bassett & Silver 1966, Baumgartl et al. 1968, Bovill 1963, Chavez et al. 1967, Leearh et al. 1967, Hjelmstedt 1968) or studies of blood flow and vascularization of the fractured bones (Abramson 1962, *Handbook of Physiology* 1963, Lorimier et al. 1946, Sun Shik Shim 1968, Van Dyke et al. 1965), next to nothing is known about the existence and duration of circulation changes in the skin and muscles of a fractured extremity in man (Medlars 1967). The aim of the present study is to obtain some data on these points.

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			l in ll lo t ompll t		(12)	
10	I	?2	I ract rı l l lx	15	Metal ı l te (7)	4
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12	I	47	Fract tib et fib l dx disloc	22	Metal plate (10)	5
13	I	36	I ract t biae dia physalis l dx dislocata Pseudarthrosis	30 after 1st oper 3 after 2nd oper	1st oper cerclage 2nd oper nail	0
13 a				32 6		2
13 b				36 9		6
13 c				39 12		9
14	M	21	I ract tib et fib l dx	36	Metal plate	28
15	M	55	I ract cruris l sin	40	Metal plate	3?
16	M	19	I ract tib et fib l dx	56	Metal plate	40
17	M	51	Fract tib l sin	56	Metal plate (12)	40
18	M	?8	I ract cruris l sin	48	Nail	40
19	F	4?	I ract cruris l sin	72	Metal plate	60

Table 1

Patient no	Sex	Age	Diagnosis	Time between fracture and investigation (weeks)	Type of fixation (no of screws)	Patient walks (weeks)
1	M	36	Fract tib et fib l dx disloc	$^5/_7$	Metal plate (13)	0
2	M	25	Fract tib et fib metaphys l sin disloc	9	2 metal plates (4 and 7)	0
2 a				15		0
3	F	30	Fract tib et fib diaphys l sin disloc	11	Metal plate (7)	1
4	M	21	Fract tib et fib l sin disloc	12	Metal plate (13)	3
4 a				17		8
5	F	50	Fract malleolaris l sin disloc	12	Cerclage (3)	1
5 a				14		3
6	M	46	Fract tib et fib l dx	56	Metal plate (8)	44
7	M	19	Fract tib et fib l sin disloc	60	Metal plate (9)	48
8	M	60	Fract malleoli et syndosmosinis fib l dx Dislocatio gravis	14	Sutura ligamenti et capsulae (2)	2

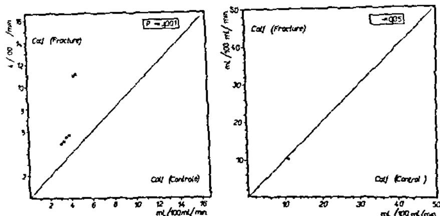


Figure 1 A and 1 B Muscle blood flow in the calf of a fractured extremity (ordinate) related to the calf blood flow of the intact control leg (abscissa) Unfilled circles—blood flow values in subjects investigated 9–18 months following the fracture Figure 1 A The average blood flow values measured at rest Figure 1 B The average blood flow values measured during 2 minutes of reactive postischemic hyperaemia

of the blood flow through the corresponding segments of the healthy extremity At the same time no unequivocal relationship was found between the degree of blood supply in the lower leg and that in the foot

In the subgroup investigated 9–18 months following the fracture no difference was found in the muscle and the skin blood flow between the intact and the fractured extremity (Figures 1A 2A—unfilled cir

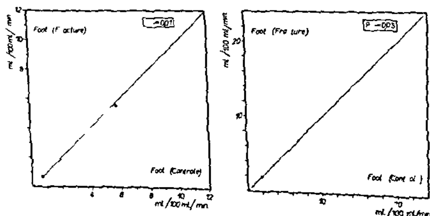


Figure 2 A and 2 B Skin blood flow in the foot For description see Figure 1

MATERIAL AND METHOD

Altogether 19 patients (13 men and 6 women) aged between 18 and 60 years (M = 36 years) without any symptoms of cardiovascular disorder with a unilateral tibial or tibiofibular fracture (9 on the right, 10 on the left leg) were investigated. Further details concerning the investigated subjects are given in Table 1.

The time lapse between the fracture and the investigation varied from 1 week to 18 months. In 4 patients the investigation was repeated at 2 to 6 week intervals.

On the day of the accident the fragments were replaced surgically and fixed by means of AO metal plates and screws (nailing was used in two cases). The operation was carried out under Fluothane narcosis (in one case under lumbar anaesthesia) in a bloodless operative field and lasted 55–130 minutes. In no case was the extremity immobilized with a plaster bandage. Within 11 weeks (on an average) the patients were allowed to place full weight on the injured extremity. Up to that time they could move on crutches and practise gymnastics.

The arterial blood flow through the vascular bed of the lower leg muscles and the cutaneous bed of the foot was measured by venous occlusion plethysmography. Flexible air filled rubber cuffs with a double wall (segmental or terminal plethysmographs) according to Dohn (1956) were used. The cuffs adhered with moderate pressure to the investigated segment (40–50 mm H_2O) and enabled measurement of the blood flow without any discomfort even in the fractured extremity. Pressure changes in the plethysmographic cuffs were recorded by means of pressure receptors (0–30 mm Hg, Elema – Sch.) on a Mingograph 81 (Elema – Sch., Stockholm). For a more detailed description of the method, see Graf & Westersten (1959) and Graf (1964). The same arrangement was also used to measure the venous capacity (compliance). The volume change in the investigated segment induced by a change in the occlusive pressure in the range of 0–60 mm Hg was taken as a relative measure of the distensibility of the capacitive vessels.

All the investigations of blood flow rate and venous capacity were carried out simultaneously on comparable segments of the healthy and the fractured extremity respectively. The arterial blood flow was measured repeatedly during rest and in the course of the first two minutes of reactive hyperaemia induced by a 4 minute long arterial occlusion (for the skin blood flow) or an arterial occlusion lasting likewise 4 minutes and including one minute of ischemic muscular work (for muscle blood flow). All the blood flow values represent the means from 5–8 measurements.

RESULTS

In the majority of cases significantly higher blood flow values both in the calf muscles and in the acral skin bed of the foot were found in the fractured than in the healthy leg (Figures 1A, 2A). The calf blood flow (muscle) in the fractured extremity averaged for the whole group 7.1 ml/100 ml per min and in the foot (skin) 4.2 ml/100 ml per min. These values correspond to 18[illegible] and 212 per cent respectively.

through the foot was 4.6 ml/100 ml per min, i.e. 242 per cent of 1.9 ml/100 ml per min in the control extremity ($P < 0.01$).

The mean blood flow values during the first two minutes following the end of ischaemia in the reactive hyperaemia showed a tendency for the differences between the fractured and the intact extremities to diminish both in the calf muscles (23.0 ml/100 ml per min in the fractured against 16.7 ml/100 ml per min in the intact, i.e. 138 per cent) and in the skin vascular bed (10.0 ml/100 ml per min against 6.9 ml/100 ml per min, i.e. 145 per cent). Nevertheless, the differences were still statistically significant ($P < 0.05$) (Figures 1B, 2B).

We designated the ratio of the blood flow in reactive hyperaemia to that at rest as 'tonal reserve'. This reserve was very low in cases with markedly enhanced blood flow due to bone fracture—in Group A (Figure 3) it was down to 2.65 and in Group B to 3.51, compared to the control values of 4.35 in the intact extremity. This ratio expresses also a considerable decline of the resting vasomotor tone in the fractured extremity.

As could be expected, no difference in reactive hyperaemia of muscle and skin between the healthy and the fractured extremity was found in the subgroup investigated 9–18 months following the fracture. In this subgroup there was no obvious local oedema in the injured leg. In fact, the mean blood flow values and the peak flow in some of the patients of this group were even lower during the course of reactive hyperaemia in calf muscle of the fractured extremity. A control investigation of the muscle blood flow by the ^{133}Xe clearance method corroborated this finding (Delius & Kellerova, unpublished observation).

Changes in the vascular capacity of the calf segment of the fractured extremity were not unequivocal in comparison with the constant finding of the markedly increased blood flow in this region. (A) The venous capacity in the calf segment of the injured extremity was significantly higher than in the opposite uninjured segment in 6 subjects ($P < 0.01$ at congesting cuff pressures of 40 and 60 mm Hg) (Figure 3, Group A). (B) Rather lower values were found in 5 patients (Figure 3, Group B). (C) Practically no differences in the vascular capacity of the calf segment were found in the group investigated 9–18 months following the injury (Figure 3, Group C, N = 8).

An examination of the blood flow in these subgroups showed that in Group A (with increased vascular capacity of the calf segment on the fractured side) the muscle blood flow at rest is significantly higher (11.03 ± 3.3 ml/100 ml per min) than in Group B with a smaller

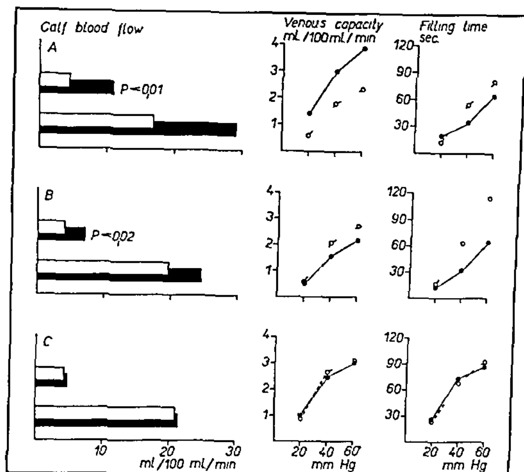


Figure 3. Values of blood flow (left columns), venous capacity (middle) and filling time (right) in three subgroups A, B and C (for specification see text). Black columns and heavy lines represent the values obtained from measuring in the fractured extremity, white columns and dashed lines—values from intact control extremity. The upper double columns in all subgroups represent blood flow values at rest, the lower double columns values of blood flow in reactive hyperaemia

cles (Figure 3C) when evaluated as a group. An intra-individual comparison had, however, shown the respective values for muscle and skin blood flow to attain in some cases as much as 158 and 154 per cent of those in the intact extremity.

If this subgroup (investigated 9–18 months following the accident) is omitted from the evaluation, the mean blood flow through the muscle of the injured extremity in the rest of the patients is 9.3 ml/100 ml per min, i.e. 216 per cent of the value in the healthy extremity, 4.3 ml/100 ml per min ($P < 0.01$). The corresponding skin blood flow

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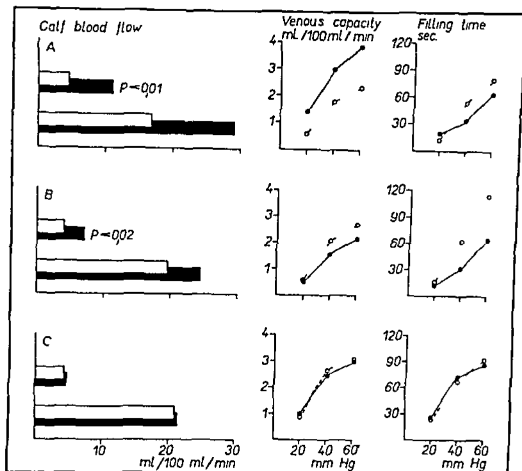


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tion that in the majority of cases there is no further increase of the blood flow after the thirteenth week after the fracture

Data obtained from the subgroup investigated 9–18 months after the fracture lead us to conclude that in the absence of complications during the healing process the originally increased blood flow values in the calf (muscle) and foot (skin) become normal once again which may be ascribed more or less to the completion of the healing process and gradual normal loading of the extremity

The tendency for the difference in blood flow values between the injured and the intact limbs during reactive hyperaemia to level out may be explained by the fact that the relative ratio of the increased blood flow due to the fracture loses its significance at peak hyperaemia Nonetheless even during this situation of reactive hyperaemia the differences between the intact and the fractured limb persist at the limit of statistical significance this again implies the presence of further factors affecting the vascular bed

An intra individual comparison of the degree of increased blood flow failed to give any correlation between the measured values in the muscle and the skin regions a fact which is probably associated with the relatively high reactivity of the skin—mainly the acral vascular bed to outside stimuli thermal changes etc

An analysis of the causes and the mechanisms that induce an increased blood flow through the calf and the foot vascular bed of the fractured extremity must take into account several factors Changes in blood supply of these tissues were noted already in the first and second week following the fracture At this early stage predominantly local and reflex effects associated to the trauma itself may be presumed to be causally involved enhanced local metabolism changes in pH pain lesion of nerve tissue or ischaemia during operation An increase of vascular volume and blood flow in the muscle and the bone vascular bed is induced in a relatively short time not only by the healing process itself (Abramson 1962 Baumgartl et al 1968 *Handbook of Physiology* 1963 Rivs et al 1967 Rhinelander et al 1968 Sun Shik Shim 1968 Van Dyke et al 1965 Wray 1964 Wray & Lynch 1959) but also by the immobilization of the limb (Hulth & Olerud 1960 1961 Imig et al 1963 Semb 1966 Stulcová & Hudlická 1967) as has been shown in animal experiments The action of these mechanisms we presume to be cumulated and as such responsible for the observed increase in blood flow Nevertheless we incline to the view that the increased blood flow in the muscle is to a major extent part of the pathophysiological picture

vascular capacity (6.96 ± 1.8 ml/100 ml per min) ($P < 0.05$). As regards clinical symptoms, patients of Group A showed a *greater proneness* to oedema formation in the fractured extremity.

The time needed to attain peak volume of the investigated calf segment from the start of the occlusion was designated as *filling time*, which depends on congesting cuff pressure, vascular tone, state of vein filling and, above all, size of arterial influx. The curve for the relationship between the height of the occlusive pressure and the filling time of the investigated segment, plotted from values measured on the fractured extremity with a high blood flow, shows a shortened filling time during congestion in comparison with the intact or healed limb (Figure 3).

DISCUSSION

Acute and chronic experiments with artificial fractures in animals (Lexer 1904; Rhys et al. 1967; Rhinelander et al. 1968; Sun Shik Shim 1968; Wray 1964; Wray & Lynch 1959), which show increased blood flow and increased volume of the resistance and capacity section of the vascular bed in the fractured limb, justified the assumption that a fracture in man might likewise induce changes in the blood flow of individual compartments of the vascular bed of the limb. Apart from Giebel (1964), who found increased temperature of the skin in the area of the fracture as late as three weeks after the accident, and Baumgartl et al. (1958), who found by angiography a denser vascular pattern, enlarged blood vessels and a faster flow of a contrasting substance in extremities with tibial fracture, we have not come across reports that deal specifically with haemodynamic changes in the muscle and skin vascular bed of limbs accompanying non-complicated fractures of the long bones in man.

A uniform finding in our group of subjects was a significant increase of blood flow through the calf and foot vascular bed of the injured lower limb.

Neither an evaluation of the entire material nor repeated individual evaluations of the data over a period of 1–22 weeks following the fracture showed any *correlation between blood flow and the time lapse* after the accident. Since our patients were investigated at various intervals after the injury and at different stages of the healing process *of the fracture*, we could not follow more closely the evolution of changes in the blood flow. But the overall trend permits the assump

After 9–18 months following the fracture the enhanced muscle and skin blood flow in the fractured leg mostly had returned to normal. Nevertheless in some subjects we found higher values even after this time.

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of the fracture itself and that the haemodynamic changes accompanying muscular atrophy due to inactivity during immobilization of the limb are an additive factor. This assumption is supported by our failure to find any correlation between the calf blood flow values and the degree of the muscle atrophy—if it was present—qualitatively assessed on the basis of clinical investigation. The extremity was not completely immobilized during the healing period; the patients had restricted freedom of limb movement and began to walk and put pressure on it relatively early. In addition, an increase in the calf blood flow was found to be accompanied by a significant increase of blood flow in the acral skin region of the foot. It would then seem that a rather important vasodilatory reaction takes place in the fractured limb which affects not only various tissues (muscle, skin) but also limb segments remote from the fracture area and various sectors of the consecutive vascular bed, as implied in the parallel changes observed in the capacitance vessels.

An experimental correlate of this described decline in vasomotor tone in the fractured limb might be seen in the work by Wray (1964) and Wray & Lynch (1959) who found increased values of blood flow in the femoral artery following a tibial fracture in the dog and by Ray et al. (1967) who found by means of labelled albumin in rabbits that an increased blood volume persists in the tissues of the limb as late as eight weeks after the fracture.

SUMMARY

In a group of 13 men and 6 women aged 18–60 years, with unilateral tibial or tibio-fibular fractures (9 right, 10 left) the calf (muscle) and foot (skin) blood flow was investigated by means of venous occlusion plethysmography simultaneously in the fractured and intact legs.

In subjects examined 1 to 22 weeks following the fracture we found a significantly higher muscle blood flow in the calf segment of the fractured extremity, on an average 9.3 ml/100 ml per min (216 per cent) in comparison with the intact limb, 4.3 ml/100 ml per min ($P < 0.001$) and a higher skin blood flow of the foot, 4.6 ml/100 ml per min (242 per cent) against 1.9 ml/100 ml per min ($P < 0.01$).

In the course of reactive hyperaemia induced by 4 minutes of ischaemia, there was a tendency for the difference in blood flow values between the injured and the intact limbs to level out, but they still remained on the border of significance ($P < 0.05$).

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TRANSPLANTATION OF PEDICLE BONE GRAFTS TO FRESH SKELETAL DEFECTS AND DEFECT PSEUDARTHROSES

An Experimental Study

K BAADSGAARD

Received 29 ix 69

In a previous paper Baadsgaard & Medgyesi (1965) reported on the survival of pedicled cancellous and cortical bone grafts With the technique used pedicled cancellous grafts were found to survive the detachment from the donor site In the pedicled cortical grafts most of the osteocytes disappeared while the blood supply and thereby the osteogenetic effect was preserved The literature on the subject was reviewed

Later Medgyesi (1965) studied the chances that pedicled cancellous bone grafts had of healing in a necrotic recipient site He demonstrated that some revascularization and invasion of new formed bone may occur by way of the pedicled bone graft Furthermore Medgyesi (1968) investigating the function of the muscle pedicle found that the most detrimental factor to the blood supply of a bone graft through a muscle pedicle is torsion of the pedicle while flexion and tension affect the nutrition of the graft less

The object of the present study was to investigate the ability of pedicled cortical bone grafts to heal a total defect in a long bone

MATERIAL AND METHOD

The experiments were performed on 43 rabbits of mixed stock mature or nearly mature in the age range 6 to 1? months.

The rabbit were anaesthetized by intravenous injection of Nembutal The

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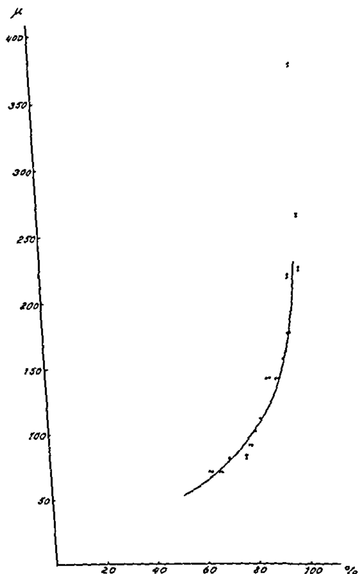


Figure 1 Self absorption curve for ^{45}Ca labelled bony tissue embedded in methyl methacrylate The curve approaches asymptotically the lines X = 100 per cent and $x = ky$

operative sites were shaved and disinfected with iodine Penicillin was *administered* prophylactically both locally and intramuscularly total dose 300 000 units

(1) 16 rabbits were used for transplantation to a fresh ulnar defect A 0 75 cm long total defect was sawn into both ulnae 3 5 cm distally to the tip of the olecranon process The calcified interosseous membrane was preserved intact so that both ulnar fragments were stable in relation to the radius From the dorsal aspect *of the proximal* end of the ulna a bone graft approx 20 × 4 × 2 mm was sawn out throughout the thickness of the corticalis On the right side a muscle pedicle consisting mainly of the m flexor carpi ulnaris was preserved The muscle pedicle covered more than half the periosteal surface It was dissected to a length so that by simple flexion of the pedicle the graft could cover the ulnar defect the proximal end of the graft against the distal fragment The graft was fixed on the side of the defect facing away from the radius as an on lay graft by two silk ligatures applied through burr holes in the ulna This fixation was entirely sufficient On the left side the operation was carried out in the same way as on the right but with a free bone graft

(2) 27 rabbits were used for transplantation to defect pseudarthroses on the ulna It has previously been demonstrated (Baadsgaard 1969a) that in rabbits defect pseudarthroses may be produced on the ulna and that these defects do not heal spontaneously By the same technique a 0 75 cm long defect pseudarthrosis was produced on the ulna 3 5 cm distally to the tip of the olecranon process At re operation 6 10 weeks later the osteosynthesis material was removed and grafting was done as described under (1) on the right using a pedicled bone graft and on the left using a free bone graft A thin plate of polyethylene was inserted between the radius and ulna to prevent invasion of callus from the radius. On both *fragments the grafts just reached healthy bone*

The rabbits tolerated the operations well Two cases of infection occurred and two of stress fracture of the radius with displacement These cases were excluded

The specimens were assessed grossly by dissection and X ray examination After decalcification the specimens listed in Tables 1 and 3 were embedded in paraffin and cut longitudinally the graft as well as the proximal and distal recipient site *being included in the section The specimens were stained with haematoxylin* eosin and with van Gieson Hansen s connective tissue staining

5 rabbits (Table 2) were labelled with tetracycline 50 mg i m at one week s *interval receiving reverin (pyrrolidine methyl tetracycline)* and terramycin (oxy tetracycline) The specimens were embedded in methyl metacrylate sawn transversely and ground to a thickness of 80 μ Several sections containing the graft *alone taken on a level with the defect* as well as sections containing graft and proximal or distal recipient site were studied by fluorescence microscopy

11 rabbits (Table 4) received ^{45}Ca 200 microcuries i v and tetracycline 100 mg i m two days before being killed Undecalcified ground sections were prepared as described above The ground sections were studied by fluorescence microscopy microradiography and quantitative determination of the ^{45}Ca uptake as described in a previous paper (Baadsgaard 1969b) In some cases there was a difference in the thickness of the ground sections on the right and left Correction was done on the basis of a self absorption curve (Figure 1) This curve was plotted on *the basis* of 60 measuring results from 12 different sections further ground after each measurement

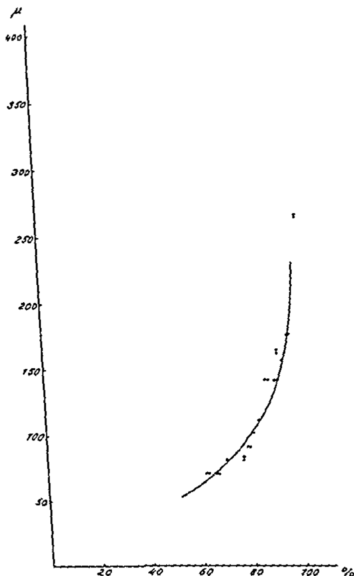


Figure 1 Self absorption curve for ^{45}Ca labelled bony tissue embedded in methyl methacrylate The curve approaches asymptotically the lines $X = 100$ per cent and $x = \lambda y$

Table 1 Transplantation to a fresh defect in the ulna
Results of histological examination

Age of graft in days	Healing				Callus formation				Vascularization of graft	
	proximally		distally		periosteally		endosteally			
	P	F	P	F	P	F	P	F	P	F
16	+	—	+	—	+++	++	+	—	+++	++
18	+	+	+	+	+++	+++	(+)	—	++	++
20	+	—	+	—	++	+	+++	—	+++	++
22	+	+	+	+	++	+	++	+	+++	+++
24	+	+	+	+	+++	(+)	+++	—	+++	+++
25	+	+	+	+	++	++	+++	++	+++	+++
29	+	+	+	+	++	+	+++	++	+++	+++
32	+	+	+	+	++	+	++	+	+++	+++
35	+	+	+	—	+++	—	+++	—	+++	++
40	+	+	+	+	++	+	+++	+	+++	+++
41	+	+	+	—	++	+	+++	+	+++	+++

P Pedicled bone graft F Free bone graft

\+ ++ and +++ indicate callus formation in a layer corresponding to ¼ ½ and the entire thickness of the graft and vascularization corresponding to ⅓ ½ and the entire graft



Figure 9 3rd week Pedicled bone graft to a fresh defect Muscle pedicle and subperiosteal bone formation

RESULTS

Transplantation to Fresh Ulnar Defect (Tables 1 and 2)

Dissection and X ray examination showed all pedicled grafts to have healed at both ends while the free grafts appeared to heal somewhat later and somewhat less constantly

Histological examination showed the muscle pedicle to consist of normal looking striated muscle with normal vessels At the attachment of the muscle to the graft the collagenous fibrils continued from the pedicle into the hypertrophic periosteum and the periosteal callus was oriented in the same direction as the muscle fibres

Periosteal hypertrophy and periosteal callus formation were most marked deep to the attachment of the muscle pedicle and almost consistently there was more periosteal callus on the pedicled than on the free grafts Occasionally there was actually an exostosis at the attachment of the pedicle An even more striking difference was found in respect to endosteal callus which started earlier and was more marked on the pedicled grafts Callus formation appeared to start at the site of the open medullary cavity on the cut surface spreading thence and growing towards the defect Older specimens often showed formation



Figure 3 Same specimen as in Figure 2 Vascularized cavity lined with osteoblasts Surviving osteocytes within the graft

Figure 4 Free bone graft from the same rabbit as shown in Figures 2 and 3 Only incipient periosteal bone formation Lacunae empty

Table 2 Transplantation to a fresh defect in the ulna Results of double labelling with tetracycline

Age of graft in days	Administration of tetracycline on day	Number of labellings P	F
16	R 9 + R 14	1	0
22	R 7 + T 14	2	1
28	T 6 + R 13 + T 20	3	2
36	T 9 + R 14 + T 20 + R 27	4	3
43	R 7 + T 16 + R 21 + T 28	3	2

R Reverin T Terramycin

of a medullary cavity in the endosteal callus the graft assuming the nature of a long bone

The pedicled grafts contained major or minor strands of cortical bone with normal looking osteocytes especially towards the periosteal surface In the free grafts on the other hand all the osteocytes disappeared Vascularization and creeping substitution it would appear start somewhat earlier in pedicled than in free grafts

Tetracycline was administered to 5 rabbits of this group and the undecalcified ground sections were studied by fluorescence microscopy The results are shown in Table 2

Administration of tetracycline on the 6th 9th day labelled 3 out of 5 pedicled grafts but none of the free grafts After the second administration on the 13th–16th day all pedicled and 3 of the free grafts were labelled It may be deduced then that the pedicled grafts have contained functioning vessels with incipient creeping substitution from about one week after the transplantation while corresponding processes did not start in the free grafts until about 2 weeks after the transplantation

Transplantation to Ulnar Pseudarthroses (Tables 3 and 4)

In principle the grafts undergo the same changes that were found after transplantation to fresh defects However certain quantitative changes are caused by the fibrous capsule of the pseudarthrosis and the poor blood supply in the region

Periosteal callus formation was slight and it was only during the first 2 weeks that pedicled grafts had the lead Endosteal callus was well marked in the pedicled grafts from the 4th week and throughout the experimental period it was clearly more advanced in the pedicled

Table 3 Transplantation to defect pseudarthroses in the ulna
Results of histological examination

Age of graft in days	Healing proximally P	Healing proximally I	Healing distally P	Healing distally I	Callus formation periosteally P	Callus formation periosteally I	Callus formation endosteally P	Callus formation endosteally I	Vascularization of graft P	Vascularization of graft I
7	—	—	—	—	+	—	+	—	+++	(+)
7	—	—	—	—	++	+	+	—	++	—
8	—	—	—	—	+	—	+	—	+++	+
10	—	—	—	—	+	+	+	+	++	+
12	+	+	+	+	+	+	++	(+)	+++	+
13	—	—	—	—	++	(+)	+	(+)	+++	+
18	+	+	+	+	+	+	++	++	+++	+
23	+	+	+	+	+	+	+	+	+++	++
32	+	—	+	—	+	+	+++	+	+++	++
34	+	+	+	—	+	+	+++	+	+++	++
40	+	+	+	+	+	+	+++	+++	+++	+++
41	—	—	+	—	++	++	++	++	+++	+++
42	+	+	+	+	+	+	+++	+	+++	+++
57	+	—	+	—	++	+	+++	+	+++	+++
57	+	+	+	+	+	+	++	++	+++	+++
62	+	+	+	—	+	+	—	—	+++	+++

Table 4 Transplantation to defect pseudarthroses in the ulna
Results of quantitative study using ^{45}Ca

Age graft in days	Callus formation periosteally P	Callus formation periosteally F	Callus formation endosteally P	Callus formation endosteally F	Vascularization of graft P	Vascularization of graft F	Measurement of ^{45}Ca c/min P	Measurement of ^{45}Ca c/min F
4	—	—	—	—	—	-	22	24
5	+	(+)	—	—	+	+	164	76
7	(+)	(+)	—	—	-	—	3	9
8	+	(+)	+	(+)	+++	+	307	112
0	++	+	++	—	+++	+	290	78
28	++	+	+	+	+++	++	363	172
40	+	+	+++	+++	+++	+++	106	153
57	+	+	+++	++	+++	+++	138	102
69	+	+	++	++	+++	+++	21	39
84	+	+	+++	++	+++	+++	161	100
9	+	+	++	++	+++	+++	71	61

than in the corresponding free grafts However the difference was most distinct in respect to vascularization the pedicled grafts showing almost complete vascularization as early as one week after the transplantation while this was not attained by the free grafts until after the 6th week

11 of the rabbits in the pseudarthrosis group were given ^{45}Ca The mean activity in 3 cross sections of the graft was measured Callus formation and vascularization in the same sections were assessed by fluorescence microscopy and autoradiography The results are listed in Table 4 On the whole they correspond to the results of investigation by traditional histological technique (Table 3)

DISCUSSION

As is apparent from Tables 1–4 the pedicled grafts showed a distinct advantage over the free grafts in respect to vascularization and callus formation during the first 6 weeks but thereafter the difference decreased From these findings it may presumably be deduced that the pedicled bone grafts also possess a more reliable healing capacity However this cannot be proved as the experimental rabbits were killed after varying periods from 1–14 weeks after the transplantation and there were but a few rabbits in each group and only 9 after

the 6th week. However, there appears to be a tendency to earlier healing of pedicled bone grafts.

Baadsgaard & Medgyesi (1965) have previously used a muscle pedicle 1 cm in length. At that time it was pointed out that the blood supply to cortical bone is rather sparse, and indeed it was observed that most osteocytes gradually disappeared from the pedicled cortical grafts. Nevertheless, it could be concluded that the muscle pedicle was able to preserve an intact vascular net in the periosteum and bone. In the present study the muscle pedicle was invariably at least 2 cm in length and flexed 180°. Zuemann (1961) demonstrated that a muscle detached from the surrounding tissues will very soon become revascularized and Medgyesi (1968) reported that flexion of the muscle pedicle has little influence upon the blood supply to the graft. And yet it must be assumed that the longer the muscle pedicle the poorer the blood supply, at least temporarily, especially when the base of the pedicle is distally as in the present experiments. Indeed, the difference between pedicled and free grafts was somewhat less marked in the present experiments than in the previous ones.

In homotransplantation to animals pre-sensitized to the donor Chalmers (1959) demonstrated that callus formation in and around the bone grafts will issue partly from surviving cells in the grafts and partly from the recipient's surrounding soft tissues by induction. This observation was later confirmed by Goldhaber (1961) in experiments using bone grafts wrapped in millipore, by Ray & Sabet (1963) using isotransplantation of bone treated with tritium labelled thymidine, and by Arora & Laskin (1964) in a sex chromatin study of isografts. Thus it may be considered an established fact that in free autologous bone grafting the graft contains surviving cells, but the quantitative ratio between the osteogenetic action by surviving cells and by induction is not known in further detail. Since comparison of pedicled with free bone grafts, where inductive action is presumed to be the same, shows a more favourable effect of the pedicled graft, the explanation must be that larger parts of the pedicled graft survive the transplantation.

SUMMARY

In experiments on rabbits the survival and healing capacity of pedicled and free bone grafts placed as on-lay grafts on fresh defects and defect pseudarthroses in the ulna were studied. The specimens were assessed

by X ray examination histological examination fluorescence microscopy and quantitative determination of the ^{45}Ca uptake

Vascularization and callus formation proved to start earlier and be more marked in pedicled than in free bone grafts The difference was most marked during the first 6 weeks

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SUMMARY

In experiments on rabbits the survival and healing capacity of pedicled and free bone grafts placed as on-lay grafts on fresh defects and defect pseudarthroses in the ulna were studied. The specimens were assessed

(1954) in an attempt to recognize the close histological resemblance to osteoid osteoma at the same time indicating a difference especially with respect to the size of the average tumor. As "benign osteoblastoma" has become the more widely accepted designation Dahlin favored in a more recent publication (1967) this latter term.

Several reports of single cases and some more recently published larger series show that the lesion is not so rare as it had at first been supposed and about a hundred cases have already been reported (Mears et al. 1965).

Despite the similarity of its histological structure and regarding both conditions as closely related lesions most authors (Jaffe, Lichtenstein, Dahlin) insist on keeping these tumors as separate entities based almost exclusively on clinical radiological differences such as the frequent absence of the characteristic pain pattern and the reactive bone and also the consistently larger size of "benign osteoblastoma" opposed to the markedly limited growth potential of the conventional "osteoid osteoma".

Unfortunately however the distinction between these two processes is not always clear and the problem of differential diagnosis is far from being solved. An increasing number of borderline lesions with features of one and the other which may be classed in either category according to personal criteria of definition have been reported and observed by us. On the other hand few cases of transition have been published.

In an attempt to elucidate the problem of the relationship between "osteoid osteoma" and "osteoblastoma" we have reviewed the material filed at the Latin American Registry of Bone Pathology which comprises 142 cases of osteoid osteoma and 42 cases of osteoblastoma studied during the last 27 years in our laboratory. We will try to demonstrate that both lesions possibly represent only anatomo-clinical variants of the same family of benign tumors of osteoblastic derivation. In our opinion it does not seem justified to retain separate entities just because of their different clinical behavior and we believe a more precise definition would be desirable in order to classify correctly the increasing number of borderline cases.

MATERIAL AND METHODS

After [illegible] careful comparative study of the clinical roentgenological and anatomopathological features of [illegible] series 142 cases have been classified as conventional [illegible] "osteoid osteoma" taking as a guide arbitrarily according to Jaffe a maximum [illegible] size of 2 cm. Byers in a recent report has adopted a similar criterion (smaller

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OSTEOID OSTEOMA AND OSTEOBLASTOMA

Closely Related Entities of Osteoblastic Derivation

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Since Jaffe's classical report (1935) the denomination "osteoid osteoma" for a very peculiar bone lesion of probably neoplastic nature has become universally accepted and familiar to orthopedic surgeons and pathologists. The typical "osteoid osteoma" is a rather common benign lesion consisting of a small core or nidus of cellular, highly vascularized tissue made up of an interlacing network of trabeculae of newly formed bone and osteoid tissue in varying proportions, and the usual presence of a conspicuous zone of sclerotic bone, the perifocal reactive zone, especially when the lesion develops in or near a cortical portion of bone. According to Jaffe the nidus tends not to exceed 1 cm at its greatest diameter but may reach, exceptionally, 2 cm and the reactive perifocal zone is much more likely to be striking when the osteoid osteoma is oriented towards the cortex rather than when it is localized within the spongiosa. In this latter case there is generally little perifocal sclerosis or it may be missing altogether.

Benign osteoblastoma, on the other hand, is the name proposed independently by Jaffe (1956) and Lichtenstein (1956) to designate a rather vascular, osteoid and bone forming benign tumor characterized cytologically by the abundant presence of osteoblasts, and which seems to have a predilection for the vertebral column. This peculiar bone tumor was first insinuated several years before by Jaffe & Mayer (1932) who reported a case of metacarpal bone lesion with the descriptive name of "osteoblastic and osteoid tissue forming tumor". After Jaffe's first description this lesion has been designated "osteogenic fibroma" by Lichtenstein (1951) and "giant osteoid osteoma" by Dahlin & Johnson

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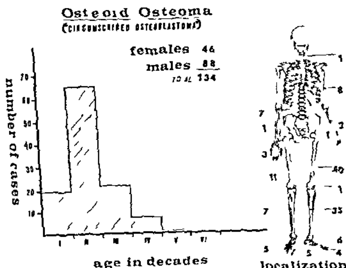


Figure 1 Skeletal distribution of 137 cases (in five site unknown) sex and age distribution of 134 cases of osteoid osteoma

classical type (2) *medullary* or *cancellous* (endosteal) 18 cases and (3) *subperiosteal* the least frequent type (3 cases) in which the nidus extends into the soft tissue raising the periosteum there is rarely reactive bone sclerosis of the underlying cortex a thin layer of periosteal bone may cover it

These cases are very difficult if not impossible to differentiate from the periosteal or peripheral type of osteoblastoma their separation being arbitrary due to their difference in size As has already been mentioned the perifocal reactive sclerosis which is so characteristic and striking in the cortical type was mild or completely lacking in 18 of our cases of the intramedullary type Some of these cases were of juxta articular location and associated with changes in the adjacent joint (Sherman 1947) The nidi were osteolytic in the majority of our cases but in approximately 25 per cent a densely mineralized central part or a ring like calcified central area (Figure 2) could be observed (Jaffe s annular sequestrum) In accordance with other authors (Jaffe Freiberger et al) we did not observe any evident correlation between the duration of symptoms and mineralization of the nidus

Cross pattern In the majority of cases the material received for examination consisted of resection specimens comprising the nidus in

or larger than *1 cm*) Most of the lesions were of the classical aspect and cortical location showing the striking reactive sclerosis but in 18 small circumscribed intramedullary (cancellous or intraspongious) and three periosteal lesions the perifocal bone sclerosis was generally minimal or completely lacking On the other hand lesions with a nidus of more than 2 cm at their greatest diameter with or without surrounding reactive sclerosis were classed as osteoblastomas (42 cases) Six of this last group were of peripherical location possibly of periosteal origin The remaining four cases of osteoblastoma were made up of *several* circumscribed lesions each of them being very similar to a small nidus of a genuine osteoid osteoma included in one wide block of reactional sclerotic bone Two of these tumors were located peripherically and juxtacortically This peculiar group of multifocal lesions hitherto not reported in the literature will be described separately under the heading of *sclerosing multifocal osteoblastomas (central* and juxtacortical)

Two cases of possibly malignant transformation of osteoblastoma together with another three tumors showing peculiar histological and clinical features suggesting a primary bone forming tumor of low grade malignancy which we have tentatively classified as malignant osteoblastoma will be the subject of a later publication after a more prolonged follow up

The fact that there are neither precise histological nor constant and clear clinical differences between these tumor types obliged us to adopt more or less arbitrarily and provisionally the size of the nidus (*more* and *less* than 2 cm) as a distinctive characteristic between osteoid osteoma and osteoblastoma In this way we *avoid at least for the moment the uncertainty of classifying* borderline lesions indistinctly in either category

CONVENTIONAL OSTEOID OSTEOMA (CIRCUMSCRIBED OSTEOBLASTOMA)

Clinical Characteristics

The incidence of sex and localization coincides in general with the data of other authors (Figure 1) There was an evident predominance of males (88 to 46) More than 50 per cent were between 11–20 years the tibia in 35 cases and the femur in 40 cases being by far the most common localizations It is interesting to note that 21 of the 40 cases were located at the upper femoral end principally neck and trochanteric region and that lesions of the metacarpal and phalangeal bones were relatively frequent (11 of the hand and 4 of the foot) The location in the terminal phalanx does not seem so rare as stated by Carroll (1953) Dunitz et al (1957) and Rosborough (1960) six of our phalangeal tumors being located at the terminal phalanx (4 in the hand and 2 in the foot)

Radiologically three types may be distinguished *according to the* location of the nidus (1) *cortical* (Figure 2) the most frequent and

cluded in a block of sclerotic bone in other cases curettings or fragmented specimens were submitted In most cases the nidus was not more than 1 cm at its largest diameter reddish in color of evidently hyperemic aspect (Figure 2) The center of the nidus was often chalky white or grayish of gritty consistency surrounded by only a small hemorrhagic ring like area

In only one case did we observe two small nidi adjacent to one another Our other cases with multiple nidi of different sizes included in one wide block of sclerotic bone will be described in the group of multifocal osteoblastomas

Microscopic aspect The histological aspect of conventional "osteoid osteoma is well known but there were some uncommon features which have not received much study up to now

The histological picture (Figure 3) represents a process of *dynamic* bone remodeling alternating active osteoblastic proliferation with formation of osteoid and coarse fibered immature irregularly *mineralized* bone trabeculae (which we prefer to call reticular bone) with osteoblastic bone resorption separated by loose connective tissue rich in hyperemic capillary blood vessels In the *central part of* the nidus the reticular calcified bone tissue may *predominate* and is responsible for a roentgenographic image generally *denser than* normal bone on the other hand the osteoid tissue can be more abundant in this area causing a translucent *image Sometimes* a central osteoid area alternates with a reticular one *followed toward* the periphery by another osteoid area This is responsible for the *roentgenographic* aspect known as annular sequestrum (*Figure 2 C*) *Whether* the lesion is wholly or partly mineralized at the time of removal *is dependent* on the phase at which this cycle is interrupted and not on the total duration of time the nidus was present (Johnston) *The surrounding* sclerosis may vary from cancellous bone tissue made up *of thickened* trabeculae separated by richly vascularized connective *tissue* to a densely sclerotic bone tissue of compact structure sometimes with genuine Haversian systems It is interesting to note the relationship between capillaries and bone formation in the "nidus It is common finding for the osteoid trabeculae to form around the hyperemic capillaries surrounding them like a ring (Figure 3) The complete *maturation* of these trabeculae often takes place very clearly from the center *to the* periphery becoming larger but keeping their vascular relationship and becoming more and more similar in shape to the Haversian type Generally and whatever its



Figure 2 Case No 20232 15 year old female Typical roentgenological (A C) macroscopical (B) and microscopical aspect of an osteoid osteoma of the fibula showing dense calcification of the central part of the nidus which demonstrates an irregular dense network of calcified reticular trabeculae (a) with less mineralized osteoid and reticular trabeculae at the periphery (b) and the perifocal sclerotic mature bone (c) D Case No 15490 15 year old female Typical nidus surrounded by sclerotic bone Note the predominance of calcified bone trabeculae and the scarce amount of osteoid tissue in the nidus (a)

present in this region It is highly probable that the not uncommon findings of perivascular nerve fibers could account for the characteristic pain pattern of this process

BENIGN OSTEOBLASTOMA
("GENUINE OSTEOBLASTOMA")

The majority of cases in this group correspond to the classical forms of osteoblastoma showing a nidus of more than 2 cm The incidence concerning sex age and localization is shown in Figure 4

Comparing our observations with those of "benign osteoblastomas of other authors an evident male preference (31 to 11) was observed by us compared to a slight male predominance (Giannestras & Diamond 1958 Dahlin & Johnson 1954) and female predominance (Jaffe 1958) of other authors The ages varied from 4 to 54 years more than 50 per cent being under 20 years of age Incidence under 10 years (7 of 38 cases) is not rare (18 4 per cent) and is similar to conventional osteoid osteoma (17 2 per cent)

The localization varied greatly With exception of the spine (including sacrum 9 cases) and other short and flat bones (rib 3 iliac 3) there was no predominance of any bone

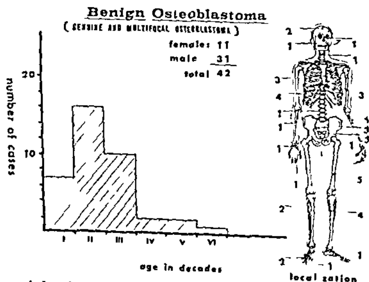


Figure 4 Location and age incidence of 42 cases of genuine osteoblastoma

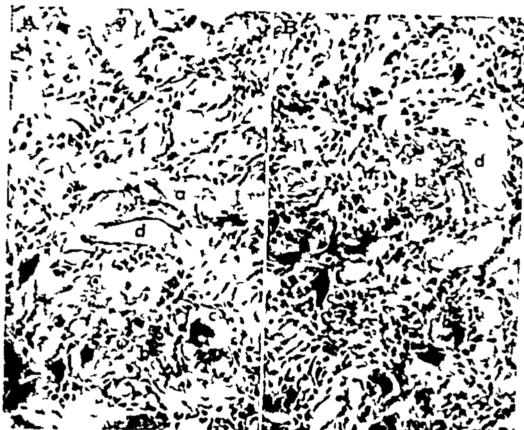


Figure 3 Case No 19078 11 year old male Photomicrographs of typical osteoid osteoma of the tibia at high magnification A B Active new formation of osteoid (a) and incompletely calcified reticular bone trabeculae (b) surrounded by rows of osteoblasts alternating with giant cells of osteoblastic type (c) separated by connective tissue rich in dilated and hyperemic capillary vessels (d) (A B × 400)

stage of development the nidus of osteoid osteoma resembles to a marked degree a focus of membranous osteogenesis with the difference that in the first an anarchic alternation of osteoblastic apposition and osteoclastic bone resorption can be observed very similar to that observed in the *active phases of Paget s disease In fact* areas of more mature bone tissue with a typical mosaic pattern can be not infrequently observed With a few exceptions we could not find a predominance of osteoid tissue in the nidus On the contrary most of the cases had a *definite predominance of reticular* more or less well mineralized bone tissue

Another fact not previously reported has been the presence of multiple tiny nerve fibers in the periphery of the nidus accompanying the abundant hyperemic arterial and venous type vessels which are always

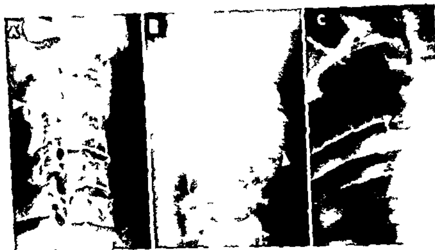


Figure 6 A B Case No 14873 14 year old male A Roentgenogram B Tomography of an osteoblastoma of the apophysis of the third cervical vertebra C Case No 19780 11 year old male osteoblastoma of the 6th rib In both cases the lesion is central (medullary) and shows patched central calcification

striking reactive sclerosis developing either near or in the cortical portion of bone Several of these lesions had been classified by us previously as osteoid osteoma and are denominated by Lichtenstein "osteoid osteomas of unusual size (Figure 5) Microscopically (Figure 8) they showed new formation of immature (reticular) bone and/or osteoid trabeculae within a richly vascularized connective stroma The amount of cells (osteoblasts osteoclasts and fibroblasts) connective stroma osteoid and bone tissue was extremely variable in these tumors When the microscopic aspect is compared with that of the conventional osteoid osteoma larger production of osteoid is generally found in this tumour type with only a discrete amount of reticular calcified trabeculae but in many cases maturation of the osteoid tissue tending toward reticular or laminar bone and heavily mineralized central areas with Pagetoid patterns can also be observed Only infrequently do conspicuous microscopic differences exist between both tumor types and these lie principally in their structural organization Whilst in the circumscribed form ("osteoid osteoma) there seems to be a more organized structure with maturation of the nidus towards its periphery in the genuine osteoblastoma the distribution of the osteoid and reticular bone has a less organized pattern The whole lesion may be found to be in the same stage of development showing a more con

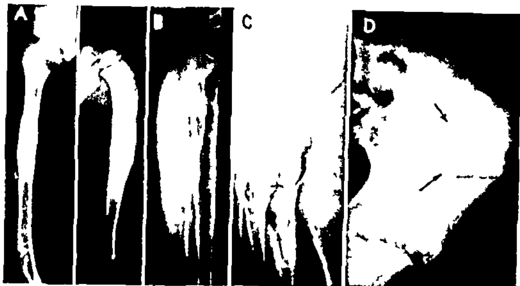


Figure 5. Four cases with large nidi varying from 2 to 6 cm representing intermediate stages of cortical (A, B) and central (medullary) lesions (C, D) with slight or conspicuous reactive sclerosis. Such conditions are classified by Lichtenstein as "osteoid osteoma of unusual size" and are classed by us in the group of osteoblastomata. A. Case No. 14746. 5 year old boy. Recurrence of an osteoid osteoma of the humoral diaphysis operated six months earlier. B. Case No. 12693. 6 year old boy. Upper third of ulna. Curetted, irradiated, and later amputated because of serious effects of radiation. C. Case No. 17532. 29 year old male. Proximal end of metatarsal bone. D. Case No. 6447. 14 year old male. Innominate bone.

The duration of symptoms until the first consultation varied from one week to two years, with approximately six months in the majority of cases. Therefore, in this group the evolution has been more rapid than in the classic "osteoid osteoma", which is in accordance with its predominantly lytic nature and less limited growth which causes pain, swelling, discomfort and premature functional disability and thus requires earlier medical treatment. Pain was the principal symptom. It was generally reported as being intense. Nocturnal intensification of pain or relief by aspirin was mentioned in only a few cases.

Medullary (Cancellous) and Cortical Osteoblastoma

In this group are included most cases (31) of genuine or ordinary osteoblastoma characterized by an osteolytic lesion of more than 2 cm localized in the great majority centrally in the cancellous part of the bone and showing, generally, only scarce or no histological or radiological evidence of perifocal sclerosis (Figure 6). Ten cases showed a



Figure 6 A B Case No 14874 14 year old male A Roentgenogram B Tomography of an osteoblastoma of the apophysis of the third cervical vertebra C. Case No 19780 11 year old male osteoblastoma of the 6th rib In both cases the lesion is central (medullary) and shows patched central calcification

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spicuous vascularization accompanied by more compact masses of hypertropic osteoblasts and a very active new formation of osteoid and immature bone trabeculae Only exceptionally may a certain number of mitotic figures appear causing possible confusion with osteosarcoma But the lack of evident cellular pleomorphism and of atypical mitotis permits a malignant osteoblastic tumor to be rejected as a diagnosis

Periosteal (Peripheral) Osteoblastoma

Six cases in our series seemed to be of periosteal origin Two similar cases were reported by Lichtenstein in 1964 Radiologically they must be differentiated from the so called osteoma in its cranial localization myositis ossificans periosteal osteoma and osteochondroma (sesil type) Two cases were located in the cranial bone frontal and occipital respectively and one in the jaw This tumor which showed an exophytic growth of large size recurred after surgical excision The histological and roentgenological picture the same as the evolution were different from osteofibroma The three remaining cases were localized in the humerus radius and in the ninth rib (Figure 7) This last tumor showed erosion of the outer part of the cortex its periosteal origin with secondary penetration of the cortex or a cortical origin with exophytic growth being questionable (Figure 7 C D) All these cases had a similar histological aspect identical to that of the other cases of genuine osteoblastoma but the perifocal bone sclerosis was generally lacking a thin shell of newly formed periosteal bone covering the lesion

MULTIFOCAL SCLEROSING OSTEOBLASTOMA (*MULTIFOCAL OSTEOID OSTEOMA*)

This is a peculiar relatively rare type of osteoblastoma hitherto not reported in the literature The cases described by Tavernier et al (1949) under the name exostosing form of osteoid osteoma are possibly post-traumatic hyperostosis or myositis ossificans We have observed two different types one *medullary* (central or endosteal) and a second peripheral (juxtacortical) type of probably periosteal origin with two cases in each group

The roentgenological and above all the macroscopical aspect showed more than one circumscribed lesion of a size similar to that of a central nidus of *osteoid osteoma* all enclosed in a single block of sclerotic

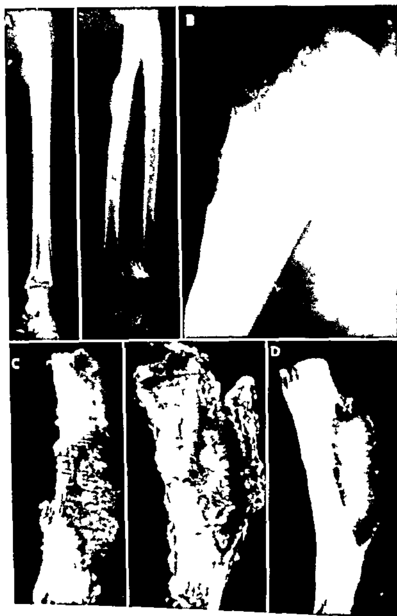


Figure 7 Different a pects of periosteal osteoblastomas A Case No 16? 7 30 year old male Lateral and antero posterior roentgenogram of non sclerosing peripheral lesi n of the upper th rd of radius B Case No 1 916 19 year old male Similar lesi n but of the upper th rd of the humerus with a thin shell of newly formed

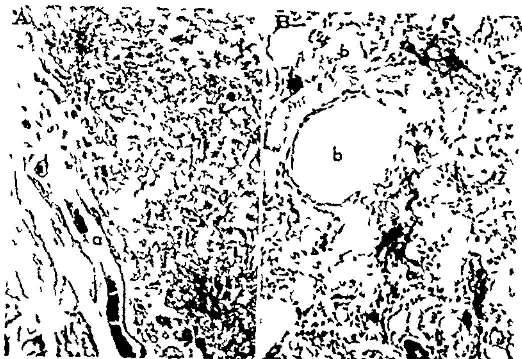


Figure 8 A, B. Photomicrographs showing the microscopic aspect of a genuine osteoblastoma at lower (A) and higher magnification (B). Case No 19784. Lesion of the third cervical vertebral illustrated in Figure 6 A and B. The histological pattern is very similar to that observed in a conventional osteoid osteoma showing in this case a somewhat more intense vascularization with numerous dilated and hyperemic capillary blood vessels at the peripheral (a) and central (b) areas of the lesion (A × 120, B × 200).

bone. In one central case we found three separated, rather large foci in the sternum and the other represented the final stage of a lesion of the humerus after incorrect treatment.

A similar case has been reported by Goidanich & Battaglia (1959) and Mears et al. (1965). It is possible that other authors would prefer the denomination "multifocal osteoid osteoma". More interesting are the two cases of juxtacortical location localized in the ethmoid and in the pubis respectively. Roentgenological and pathological examination of the resection specimen showed multiple circumscribed images of

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subperiosteal bone. The periosteal origin seems evident in both cases. C and D. Case No 10609, 23 year old female. C. Photographs and D roentgenogram of a large peripheral lesion of the 9th rib. In this case the periosteal or cortical origin can be questioned.



Figure 9 A B C Case No 10 46 40 year-old female Roentgenological (A) and macroscopical appearance of juxtacortical *(peripheral)* multifocal sclerosing osteoblastoma *of pubis Photograph (B) and roentgenogram (C) of the gross specimen show clearly the juxtacortical location and the various hemorrhagic focal lesions of different sizes enmeshed in a mass of sclerotic bone The gross aspect of each of these focal lesions is identical to a "nidus" of conventional osteoid osteoma*

nidal type of different sizes each with a picture both macro and microscopically identical to that of "osteoid osteoma surrounded by a dense block of sclerotic bone (Figure 9)

DISCUSSION

According to our observations and those of other authors it became clear that the so-called osteoid osteoma and benign osteoblastoma constitute closely related processes that may be regarded as members of the same family of benign bone tumors of osteoblastic derivation The



Figure 10 Case No 13,68 5 year old boy Transformation of an osteoid osteoma incorrectly treated at the beginning into an osteoblastoma A Initial roentgenological aspect August 1962 with the appearance of conventional osteoid osteoma B Recurrence after curettage biopsy December 1962 The central osteolytic lesion has increased considerably in size and an evident periosteal new bone formation is observed Partial excision of the lesion was followed by small cortical grafts After a new recurrence a wide block resection of the tibial diaphysis was performed with replacement by fibular graft C Roentgenogram from December 1966 with no signs of recurrence This case clearly illustrates the possibility of transformation of a small circumscribed lesion with the aspect of conventional osteoid osteoma into an indisputably genuine osteoblastoma and afterwards into a multifocal lesion following incomplete excision In April 1968 the patient was free from symptoms

name osteoid osteoma proposed by Jaffe in 1935 despite its universal acceptance does not seem completely correct to us The osteoid tissue supposed to be characteristic is the one least evident in its histological picture in which with the exception of a few cases there is always a predominance of reticular (calcified) bone over the osteoid tissue If we must accept the name osteoid to designate a tumor it would cer

tainly be better employed for what was described by Jaffe and Lichtenstein as "benign osteoblastoma" in which the production of osteoid tissue is always striking This seems to be the reason why Dahlin & Johnson (1954) classified it as "giant osteoid osteoma and Lichtenstein (1965) more recently denominates the lesions with large nidi as osteoid osteoma of unusual size because they are surrounded by more or less obviously reactive bone sclerosis In order to facilitate the definition and classification we would like to suggest the name "osteoblastoma for the tumors belonging to *both* groups This is a denomination which better emphasizes the close relationship between the tumoral type and the cell of origin the *osteoblast* which is always present in the microscopic picture of all these lesions The use of the term osteoblastoma with various subdivisions corresponding to the different anatomo-clinical forms has in our opinion the advantage of unifying the nomenclature of this closely related group of bone tumors

Finally there is a third type which has not yet been reported and which is denominated by us as multifocal sclerosing osteoblastoma which may be of central (medullary) or peripheral (juxtacortical) location and of possible periosteal origin Our proposed tentative classification is the following

Circumscribed osteoblastoma (Osteoid osteoma) Nidus less than 2 cm	*Cortical* Medullary (cancellous) Periosteal	*Sclerosing* With very little or no sclerosis
Genuine osteoblastoma (Benign osteoblastoma") Nidus larger than 2 cm	*Medullary* (cancellous) Periosteal Cortical	*With very little* *or no sclerosis* Sclerosing
Multifocal osteoblastoma	Medullary Peripheral (juxtacortical)	Sclerosing

In our opinion the adjective benign should be avoided on the one hand because it is unnecessary and redundant analogous with other bone tumors well known to be benign and which do not bear this adjective and on the other and still more *important our studies* if we except the circumscribed osteoblastoma (osteoid osteoma") demonstrate that this is not so benign as it was supposed to be We do not have a sufficiently long follow up of all our cases (as occurs with others reported in the literature) but we have had recurrences in four of them



Figure 10. Case No. 13068. 4 year old boy. Transformation of an osteoid osteoma incorrectly treated at the beginning into an osteoblastoma. A. Initial roentgenological aspect, August 1962, with the appearance of conventional osteoid osteoma. B. Recurrence after curettage biopsy, December 1962. The central osteolytic lesion has increased considerably in size and an evident periosteal new bone formation is observed. Partial excision of the lesion was followed by small cortical grafts. After a new recurrence, a wide block resection of the tibial diaphysis was performed with replacement by fibular graft. C. Roentgenogram from December 1966 with no signs of recurrence. This case clearly illustrates the possibility of transformation of a small circumscribed lesion with the aspect of conventional osteoid osteoma into an indisputably genuine osteoblastoma and afterwards into a multifocal lesion following incomplete excision. In April 1968 the patient was free from symptoms.

name "osteoid osteoma" proposed by Jaffe in 1935, despite its universal acceptance, does not seem completely correct to us. The osteoid tissue supposed to be characteristic is the one least evident in its histological picture, in which, with the exception of a few cases, there is always a predominance of reticular (calcified) bone over the osteoid tissue. If we must accept the name "osteoid" to designate a tumor, it would cer-

stitute only different anatomico-clinical variants of one and the same bone tumor of osteoblastic derivation In order to unify the terminology we tentatively propose the term osteoblastoma" for both lesions which may consist of the following anatomico-clinical types

(1) Circumscribed osteoblastoma most frequently sclerosing and located cortically with a nidus of less than 2 cm (conventional osteoid osteoma) (2) genuine osteoblastoma most frequently with scarce or no reactive sclerosis and located medullarily (intraspongeously) with a certain preference for short and flat bones The main differences between these conditions are most probably the consequence of their locations (cortical or medullary respectively) which most likely explains the slow growth potential of the circumscribed osteoblastoma" ("osteoid osteoma) as opposed to the more active growth of the genuine osteoblastoma A third type hitherto not reported has been called "multifocal sclerosing osteoblastoma and can occur as an intramedullary (cancellous) or peripherical (juxtacortical) type

In our opinion the adjective benign should be avoided because several instances of recurrences have been reported and also observed in our series after incomplete conservative treatment The possibility of malignant transformation has also to be considered

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The authors wish to express their appreciation to all those colleagues who have collaborated by sending their material and permitting the use of their cases in this paper They also wish to acknowledge the skilful help of *Mrs Adela M de Schajowicz* and laboratory technician Miss Alicia Sens and photographer Mr O Lobos

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Cenepa & Fabiani (1965) reported recurrences in 11 of 54 cases reviewed with complete data. Furthermore, the possibility of malignant transformation after conservative (curettage) or incomplete treatment should be considered. Mayer reported recently (1967) *the case of a* 33 year old male who 13 years after curettage of a lesion at the roof of the acetabulum diagnosed by Jaffe as "benign osteoblastoma" developed an osteosarcoma of the same site. *We agree with him when he* states that "we must accept the fact that the concept of the benign osteoblastoma is still immature. The number of reported cases are too *few for us to be dogmatic". The fact that we have observed in two of* our cases a possible transformation of a pre-existent "benign osteoblastoma" into a low grade osteosarcoma after incomplete conservative treatment (curettage *followed by* radiotherapy) seems to confirm Mayer's prediction that "it may well be that, during the next twenty or thirty years, as our experience ripens, additional cases may be discovered and it may be necessary to abandon the term 'benign' as applied to this group of lesions".

This demonstrates that the genuine osteoblastoma may sometimes have an aggressive behavior, especially after incorrect treatment, similar in many aspects to a giant cell tumor (osteoclastoma).

SUMMARY

A comparative clinical, radiological and anatomico-pathological study of 142 cases of conventional "osteoid osteoma" and 42 cases of so called "benign osteoblastoma" filed at the Latin American Registry of Bone Pathology has been carried out.

All intermediate stages of foci from a few millimeters to several centimeters in size, surrounded or not by sclerotic bone, have been observed, no striking differences in the histological pattern being demonstrated in the great majority of cases. It was necessary to adopt an arbitrary criterion to separate the entities, taking as a guide the size of the nidus, classifying provisionally the lesions with a nidus of less than 2 cm as "osteoid osteoma" and the larger tumors as "osteoblastoma". Transition of a circumscribed focal lesion identical to a conventional "osteoid osteoma" into a large osteoblastoma-like process has been reported in the literature and has also been found in our series.

According to our experience, "osteoid osteoma" and "osteoblastoma" have to be considered as closely related processes that probably con-

stitute only different anatomico clinical variants of one and the same bone tumor of osteoblastic derivation In order to unify the terminology we tentatively propose the term osteoblastoma for both lesions which may consist of the following anatomico clinical types

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Institute of Medical Sciences (Bunnell Mem. Fellowship, Head: J. J. Niebauer), Presbyterian Medical Center, San Francisco, U.S.A., and Clinics of Extremity and Hand Surgery (Head: E. Moberg) and Orthopaedic Surgery (Head: C. Hirsch), University of Gothenburg, Sweden

TISSUE SURROUNDING GRAFTED TENDONS IN DOGS

A Pathomorphologic Study

S. IOSHACI, I. GOLDIE & J. J. NIEBAUER

Received 2.vi.69

Tendon grafting is a complex problem in which must be considered a number of factors such as healing at the site of anastomosis, change in morphologic features and in functional properties, influence of surrounding tissue and adaptation to a change in muscular load.

Reparative or regenerative processes which characterize the healing of a tendon transplant have recently been studied by, among others, Peacock (1965), Flynn & Graham (1965), Birdsell, Tustanoff & Lindsay (1966) and Seiffert (1967). All have found that the reparative pattern is much the same as is seen in different stages of wound healing. One question which has not yet been answered is how the reaction of the surrounding tissue influences the reparative process in the grafted tendon.

To investigate this question we have carried out a series of experiments, the purpose of which has been to study what occurs in the tissue surrounding a tendon graft and the ultimate fate of a thin tendon graft in different types of surrounding tissue.

MATERIAL AND METHODS

Experiments were carried out in 57 male and female dogs of varying races. The average weight of the dogs was 15.1 kg. Three of the animals were used for control studies and three for special radioactive investigations. Thus transplantation for morphologic study was performed in 51 dogs. The peroneus longus tendon was used as a graft to replace the Achilles tendon. Parallel to this, however, experiments were designed for comparative reasons in which the peroneus longus tendon was excised and reinserted in its own tendon sheath. In all, the 51 dogs represented 70 transplanting procedures, of which 45 were transplants for the Achilles tendons and 25 reimplantations of the peroneus longus tendon.

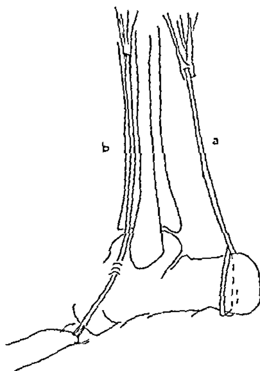


Figure 1

Figure 1 and 2. Schematic representation of the different surgical procedures (see text)

All operations were performed in general anaesthesia with intravenous administration of Pentothal and a bloodless field under tourniquet was used.

Operative Technique in Transplanting Peroneus Longus Tendon to Substitute Excised Achilles Tendon (a in Figure 1)

The hindleg was surgically prepared and draped. A longitudinal incision on the lateral border of the foot was used to expose the peroneus longus tendon which was then divided. A short curved incision was then made over the lateral aspect of the leg just below the knee joint and the peroneus longus was identified and withdrawn proximally and severed at the musculotendinous junction.

A long curved incision was made on the lateral side of the Achilles tendon from the os calcis up to just below the knee joint. The cutaneous nerves were spared; the whole Achilles tendon was severed at the incised insertion into the os calcis. A drill hole was made in the os calcis. The Achilles tendon together with its tendon sheath was dissected out and severed proximally at the musculo-tendinous junction

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Figure 3 a Transverse section of transplanted peroneus longus tendon for Achilles tendon in dog 2 days postoperatively Verhoeff's connective stain Extratendinous reaction with abundance of polynuclear leukocytes and small haemorrhages No abnormalities in grafted tendon

Figure 3 b Higher magnification of marked area in 3 a

Unloaded grafts (c and d in Figure 2)

In seventeen instances care was taken that no load be exerted on the grafted tendon This was achieved by bringing the proximal end of the tendon graft in between the tibia and the fibula to the posterior side of the leg in cases where the peroneus tendon was retransplanted and the anterior side in the cases where it replaced the Achilles tendon

In all cases excepting those in which the experiment was terminated earlier the plaster cast remained for some 4 weeks No animal was left without immobilization It was possible to keep the dogs from extensive chewing of the plaster by adding a few drops of formaline to the plaster of Paris The animals were allowed to survive after surgery for various lengths of time (Table 1)

Following the termination of the experiment in each individual case macroscopic examination and recording were made Sections were obtained for histologic study the staining used was haematoxylin and eosin and Verhoeff's connective tissue stain

RESULTS

As a general statement it can be said that loading either grafted or reimplanted tendons did not seem to alter the structural development

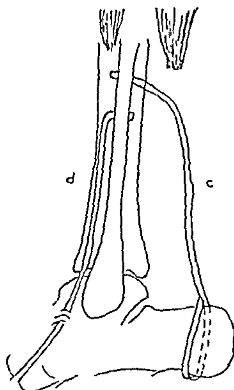


Figure 2

The peroneus longus tendon was transferred into the prepared bed and united to the musculotendinous junction of the whole Achilles tendon using a pull through technique The junction was sutured with Teflon stitches The tourniquet was removed and the distal end of the Achilles tendon was then pulled through a hole in the os calcis and sutured back to itself thus forming a loop The load on the tendon was estimated to 350 g All bleeding spots were carefully tied The skin was closed with stainless steel sutures and the leg was immobilized in a plaster cast with the knee in full flexion and the foot in semi flexion

Operative Technique in Reimplanting the Peroneus Longus Tendon (b in Figure 1)

The hindleg was surgically prepared and draped The peroneus longus tendon was exposed on the lateral side of the foot and severed A Teflon suture was attached to the end of the tendon On the lateral side of the leg a short incision was made just below the knee joint Through this the proximal portion of the tendon was identified The tendon was pulled out together with the Teflon thread The musculotendinous junction was divided obliquely An elongation suture was made the whole graft was pulled back in its original place and an end to end suture was made at the distal severance The skin incisions were closed with stainless steel sutures The leg was immobilized with a low cast with the foot in semi flexed position



Figure 4 Transverse section of transplanted peroneus longus tendon for Achilles tendon in dog 14 days postoperatively
Graft surrounded by granulation tissue with tufts growing into tendon Beginning vascularization of tendon graft Graft still completely intact with almost normal cellularity

Seven days

Macroscopic At this time there was a marked difference in the appearance of the tissues surrounding the graft The tendon was covered by a thin coat of fibrinous substance which however seemed enforced by a network of fibrils This could easily be peeled off the graft The tendon graft no longer appeared swollen but there was no shiny glittering surface Instead the surface had a dull yellow colour

Microscopic The space around the tendon had diminished but was still there The thin layer of fibroblasts forming the epitenon around

Table 1. Number of legs with different surgical procedure (Figures 1 and 2) and survival days

Days	A	B	C	D	Total
2	3	3	1	1	8
7	[illegible]	2	4	2	13
14	3	2			5
21	3	2			5
30	3	2	2	1	8
60	5	3	2	1	11
90	4	2			6
120	4	2	1	1	8
180	4	1	1		6
Total	34	19	11	6	70

of tissue events in and around the tendon. The following description thus applies to both loaded and unloaded tendons.

Transplantation of Peroneus Longus Tendon for the Achilles Tendon

Two days (Figure 3)

Macroscopic. On opening the wound small diffusely scattered haematomas were observed along the transplant. There was abnormal tissue surrounding the grafts and these were slightly swollen. Fibrinous plaques were seen irregularly spread in the grafting area. The suture regions did not disclose anything abnormal.

Microscopic. On transverse sections the tendon proper appeared slightly split up but as there was no sign of oedema or other reaction in these splits they were regarded as results of the technical handling. The collagenous bundles of the tendon were normal. The tendon was covered by a thin one cell layer of fibroblasts which was interpreted as the epitenium. Outside of this there was a fibrinous zone which seemed to wall off the tendon from the surrounding tissue. This latter gave the impression of high activity with an abundance of polymorphonuclear leukocytes. Small irregular haemorrhages were observed and occasional strands of erythrocytes which might represent open circulation and might be precursors to the formation of capillaries. Occasional mononuclears were identified.



Figure 4a. Transverse section of transplanted peroneus longus tendon for Achilles tendon in dog 14 days postoperatively.

Graft surrounded by granulation tissue with tufts growing into tendon. Beginning vascularization of tendon graft. Graft still comparatively intact with almost normal cellularity.

Seven days

Macroscopic. At this time there was a marked difference in the appearance of the tissues surrounding the graft. The tendon was covered by a thin coat of fibrinous substance which, however, seemed enforced by a network of fibrils. This could easily be peeled off the graft. The tendon graft no longer appeared swollen but there was no shiny glittering surface. Instead the surface had a dull yellow colour.

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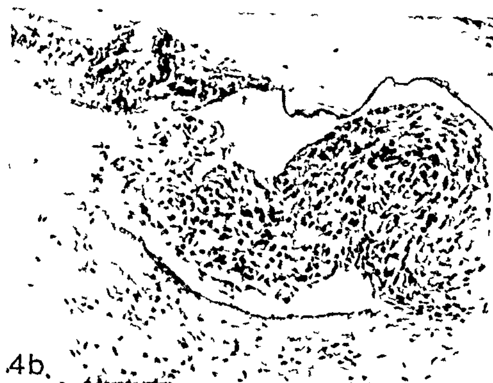


Figure 4 b. Higher magnification of granulation tuft

the graft still remained intact except for some small regions where vascular connections had been established between tendon and the surrounding tissue which was markedly increased. Occasional capillaries were now noticed to appear irregularly and some of these broke through the epitenon but did not seem to invade the tendon proper. These vessels were surrounded by a number of cells the identification of which was somewhat difficult but which were interpreted as fibrocytes. The same type of cell was seen scattered through the tissue around the tendon. Polymorphonuclear leukocytes were still seen but to a lesser degree. Small clusters of lymphocytes were observed. The surrounding tissue thus resembled true granulation tissue.

Fourteen days (Figure 4)

Macroscopic. The grafted tendon was still surrounded by a coat of tissue which had turned more fibrous but which could still be easily stripped off. This surrounding tissue having become more organized did not occupy such a large area which gave the impression that the graft was slightly thinner. No oedema was seen and the tendon was slim and slender without any naked eye abnormalities.



gure 5 a Transverse section of transplanted peroneus longus tendon for Achilles tendon in dog 60 days postoperatively
aft intimately associated with surrounding connective tissue but a border line is still apparent with some vascularization

gure 5 b Higher magnification of marked area in 5 a. Note very intimate association between graft and surrounding tissue with vessels invading graft

Microscopic As observed in sections under the microscope the surrounding tissue still appeared abundant but by now fibrous strands were more prevalent and very few polymorphonuclears were seen There were a great many fibroblasts and some mononuclears There was no longer any oedema and the space around the tendon had shrunk The epitenon was still mostly intact but occasional connections were seen between the central parts of the abundant granulation tissue and the tendon In this connecting channel like vessels were seen The number of capillaries had markedly increased in the tendon

Twenty one thirty and sixty days (Figure 5)

Macroscopic The surrounding tissue was now well organized in a comparatively fixed coat which at the end of this observation period was almost white and still could be peeled off from the tendon but with more difficulty as there were adhesions between the surrounding

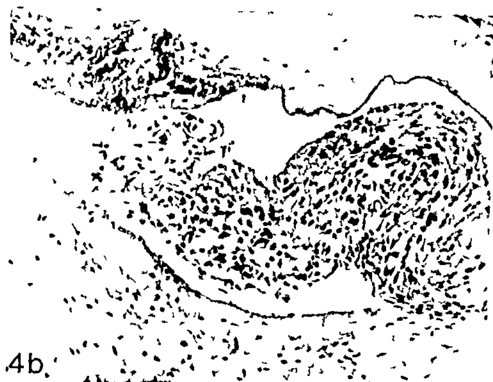


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Ninety one, one hundred and twenty and one hundred and eighty days (Figure 6)

Macroscopic By this time a functional tendon was found The tissue surrounding the tendon graft could hardly be peeled off The size of the "tendon" corresponded well in all cases to the size of the Achilles tendon of the non operated leg It was however not as pliable as the original tendinous tissue but served an equally good function as judged by the clinical result

Microscopic The original tendon graft had by now become engulfed by the reactive fibrous tissue and only in smaller patches reminiscences of the graft could be seen The differences between the original graft and the surrounding tissue were almost negligible in most places Both were highly cellular Still however there was an indication of the original epitenon border which facilitated discovery of the location of the graft in the reactive fibrous tissue This had become better organized and the fibrous strands were now observed to follow a parallel straight course The number of vessels had decreased and the overall impression was that the tissue was no longer as active as in earlier stages

To summarize it can be said the grafted tendon is replaced by an active reparative process characterized by granulation tissue which eventually turns into fibrous tissue The original thin graft becomes involved by this process in a homogenous strand of fibrous tissue the size of which corresponds to the tendon it replaces Microscopically the grafted tendon resists the invading properties of the reactive tissue for a time but finally it succumbs and is replaced by fibrous tissue in which the collagen fibres become organized in a way similar to a tendon After 180 days there is still a cellularity which supercedes that of an ordinary tendon Clinically the functional qualities remain unimpaired

Reimplantation of the Peroneus Longus Tendon in Its Own Sheath

This procedure proved to be quite innoxious to tendon sheath and surrounding tissue For this reason it has not been found of any advantage to give a detailed separate description of the macroscopic and microscopic appearance of these *control* transplantations

It can only be said that apart from a slight reaction with hae



Figure 6 a. Transverse section of transplanted peroneus longus tendon for Achilles tendon in dog 120 days postoperatively.
Graft morphologically almost identical with surrounding tissue. Border line recognizable as fibrous strand seen in higher magnification in Figure 6 b.

Figure 6 b. Marked area in 6 a of fibrous strand as remnant of border line. Note the almost identical cellularity of graft and surrounding tissue.

tissue and the tendon. The latter had shrunk somewhat and appeared to be split up in places where the adhesions were found.

Microscopic. The granulation tissue had during this time become replaced by fibrous tissue. Fibrous strands reached the epitenon of the grafted tendon and in some places they broke through and invaded the tendon where splits were present. There were no signs of the tendinous strands becoming absorbed by the invading tissue, only pushed aside. The space around the tendon was obliterated almost completely. There was rich vascularity of the fibrous tissue. In the tendon proper, which had diminished considerably, a number of vessels could be seen not only in the periphery but in the centre as well. The collagenous bundles in the grafted tendon had lost their homogeneity and appeared shrunken but structural details were still discernible and no signs of necrosis were noticed. The sutured areas were all characterized by dense fibrous tissue. Polymorphonuclear leukocytes could no longer

neus tendons in dogs after excision of the whole tendon except for a small band at the ankle joint His morphological observations correspond in detail with those of our study when we transplanted the peroneus longus tendon for the Achilles tendon without its tendon sheath

From the above observations it may be said that a tendon transplanted without tendon sheath is involved in a tissue reaction which in all respects resembles that of repair The transplanted tendon becomes involved in this tissue and subsequently it is completely replaced by the healing tissue which appears whether or not tendon graft is present

The conditions are very dissimilar in reimplantations into the intact tendon sheath This procedure does not stimulate more repair than is necessary for the severed regions to heal In this context it is of interest to point out some of the statements made by Peacock (1967) on the restoration of the gliding function He believes that a secondary remodelling process occurs which causes certain portions of the scar to undergo collagenolysis so that the scar which connects the tendon graft and the skin re forms so that normal tendon and dermis ensue He moreover states that it is inaccurate to believe that adhesions must be broken to restore mobility to the tendon Peacock has dissected a number of fingers with normal gliding tendon grafts in which this resulted from secondary remodelling so that the portion of scar which lay between the tendon and its surrounding bed ultimately resembled loose connective tissue like that normally found around uninjured tendons (paratenon) It thus appears that environmental factors of yet unknown properties may be of importance in the fate of tendon grafts

Our results also favour the theory expressed by *Peacock (1967)* According to him it may be said that the best possible tissue to surround a tendon graft is a normal digital theca This contains few cells capable of producing collagen Besides it may be so that the theca contains cells capable of producing an ultrafiltrate from plasma which improves the gliding function

Against the suspicion that the increased muscular load on the graft when it replaced the Achilles tendon could be responsible for the changed morphological picture is the fact that we saw exactly the same picture whether the tendon was loaded or not

Regarding the size of the newly formed tendon when the peroneus longus replaced the Achilles *tendon* the thickness was found to be roughly equal to the original Achilles tendon after 30 days This however was a general observation and not systematically analysed The

morrhage oedema polymorphonuclear leukocytes and slight vascular increase as a response in the earlier stages to the surgical trauma the development was completely uneventful No later reactions were observed in either tendon tendon sheath or surrounding tissue Only at the suture levels was there an increase in activity up to about 21 days after surgery In the mid portion the tendon graft retained the same size and the same structural characteristics through the control period No increased cellularity could be observed

DISCUSSION

In this investigation it has become evident that the morphologic sequence of events differs considerably in tendon grafts surrounded by different types of tissue The experimental procedures have focused attention on the influence the tendon sheath may have on repair of grafted tendon tissue

The tissue that surrounds the transplant when it is transplanted without the tendon sheath into loose connective tissue as well as the graft itself demonstrates a morphological development which in time and appearance of various structural elements corresponds to what has been shown earlier by several authors Adams already in 1860 stated that in rabbits the tissue that filled an experimental gap ultimately resembled a mature tendon histologically Conway et al (1967) excised a portion of the calcaneal tendon in rabbits The connective tissue growth in their experiment set in rapidly after the tendon had been removed with signs of regeneration as early as after two days and by 56 days there were connective tissue fibres with characteristics similar to those of mature tendons By 240 days the regenerated material resembled a mature tendon in almost all qualities except that there was no fascicular arrangement and the tissue was much more cellular than a normal tendon This apparently implies that from a morphological standpoint the grafting procedure in rabbits is superfluous as the connective tissue strand which replaces the removed calcaneal tendon resembles this in a number of details and also takes up its function This seems to be so even in dogs as in some of our unloaded tendon grafts a strand formed between the graft and the muscles This strand had the same histologic picture as the one described by Conway et al

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A study has been carried out to follow what occurs in the tissue surrounding a tendon graft and the ultimate fate of a thin tendon graft in different types of surrounding tissue

Experiments have been carried out in 51 dogs on 70 legs The peroneus longus tendon was used as a graft to replace the Achilles tendon In other experiments the peroneus tendon was excised and reinserted in its own tendon sheath Slight loading was exerted on all grafted tendons except in 6 instances

Histological studies of the grafted areas were carried out after 2 7 14 21 30 60 90 120 and 180 days

The results disclosed that loading or non loading the tendons did not seem to alter the structural development of tissue events

Histologically it became evident that an inflammatory reaction characteristic of a genuine repair process was instituted and at the time of termination of the experiments with transplanting the peroneus longus tendon into the site of the Achilles tendon a complete replacement of the tendon transplant with ingrowing connective tissue had taken place

In those experiments where the peroneus tendon was excised and reinserted into its own sheath there was complete healing at the sites of incision with the tendon completely intact

These results suggest that tendon transplants act only as a guiding matrix for the repair tissue

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increase in size seemed to occur whether the tendon was sutured to the muscle or not. This corresponds with the experiments performed by Conway et al. (1967). It also corresponds with the experiments of Elliot (1965) where he found the thickness of collagen to represent the tension which the tendon had transmitted and it was not necessarily dependent on the strength of the muscle. Passive tension in the tendon as well as increased muscular load results in increased thickness. Elliot performed his investigations on tendons from denervated muscles in young rabbits.

In the literature very divergent opinions have been expressed regarding the fate of a transplanted tendon. Mason & Shearon (1932) and Peer (1955, 1959) are of the opinion that the autologous tendon transplant will survive. An entirely opposite standpoint is taken by e.g. Skoog & Persson (1954) and Flynn et al. (1960). These latter authors believe that the tendon succumbs and only serves as a guiding matrix for ingrowing fibroblasts from the surrounding connective tissue. A third position in this question is taken by e.g., Imavoshi (1925) and Lindsay & Birch (1964). These authors believe that the peripheral parts of the transplant survive while the central portions are replaced by connective tissue after primary necrosis. Lindsay & MacDougal (1961) and Birdsell, Tustanoff & Lindsay (1966) discuss a process called "reconstitution" which involves a combination of survival and repair. Our results when we reimplanted the peroneus longus tendon in the tendon sheath indicate a total surviving tendon graft. The result when we transplanted the peroneus longus for the Achilles tendon corresponds with the opinion that the tendon transplant is entirely replaced by ingrowing connective tissue. This appears to take place along the earlier position of the mesotendon, the existence of which has previously been reported by Mayer (1916).

Thus our results could perhaps explain the differing opinions. They could to a great extent be related to the different circumstances under which the experimental transplantations have been performed and the response of the host tissue. Further experiments are necessary to confirm this definitely.

SUMMARY

Tendon grafting brings into consideration factors like healing of anastomosis, change in morphologic and functional properties, influence of surrounding tissue and adaptation to a change in muscle load. The

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Orth pedic Clinic (Head Melvin Glimcher) Harvard Medical School Massachusetts General Hospital Department of Connective Tissue Research (Head E. A Balazs) and Department of Orthopaedics (Head Carl Hirsch) University of Gothenburg Sweden

DECREASED GRANULATION TISSUE REACTION AFTER INSTALLMENT OF HYALURONIC ACID

NILS RYDELL

Received 2 xi 69

In 1958 Balazs suggested that hyaluronic acid preparations be used for replacement of the vitreous body of the eye Widder (1960) and Hruby (1961) used commercially available hyaluronic acid of bovine origin for vitreous replacement in human eyes after animal studies The hyaluronic acid preparation they used was however of low molecular weight Balazs & Sweeney (1968) pointed out the importance of using a preparation of high molecular weight and of using a method of sterilization that would not cause the hyaluronic acid polymer to degenerate and reported on a method of preparation and sterilization of hyaluronic acid This preparation was injected as a replacement for liquid vitreous into the eyes of 50 owl monkeys No adverse long term reaction was observed Hyaluronic acid is now used as a substitute for the vitreous body of the human eye in connection with operations for retinal detachment

The beneficial effect of installment of hyaluronic acid in certain joint and tendon disorders has recently been desribed (Rydell et al 1969 Rydell 1969) These studies were performed on animals but the results were auspicious and treatment with hyaluronic acid is now being introduced in human patients

During the studies of intra articular injections in normal and arthritic horse joint (Rydell et al 1969) it was observed that injections of hyaluronic acid induce a *migration of a* huge number of macrophages into the injected area without any clinical sign of inflammation It was thought that the beneficial effect observed after intra articular injections of hyaluronic acid was related to the influx of macrophages into the joint A similar cellular reaction was sometimes found to occur in

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Table 1 Subcutaneous tissue reaction to surgical skin incision with and without hyaluronic acid installation

Animals	No evaluated	Less reaction on hyaluronic acid side	Less reaction on control side	No difference between hyaluronic acid and control sides
Owl monkey	8	6	0	2
Rabbit	1	16	1	4
Guinea pig	10	10	0	0
Total	39	32	1	6

Grade 1 and the control side as Grade 2 while in two cases both sides were marked as Grade 2 Of the 25 rabbits 4 were excluded 1 of them because of death and 3 because of infection Of the remaining 21 rabbits 16 revealed less reaction on the hyaluronic acid treated side 12 classified as Grade 1 and 4 as Grade 2 and on the control side all 16 were classified as Grade 3 Four rabbits showed no difference between the two sides 3 of them were classified as Grade 1 and one as Grade 2 on each side One rabbit had smoother healing on the control side marked as Grade 1 while the hyaluronic acid treated side was marked Grade 2

None of the 10 guinea pigs was excluded All were classified as Grade 1 on the hyaluronic acid treated side and Grade 2 on the control side

With the encouraging results obtained it was believed that hyaluronic acid could also be used in decreasing connective tissue reaction around foreign body implants To obtain information on this a 3 cm long incision was made in the lower region of the thorax of 5 guinea pigs The incision was placed on each side 2 cm from the mid line of the dorsum with its midpoint over the tip of the tenth rib On each side two 1 cm long hollow polyethylene tubes with outer diameters of 10 mm and inner diameters of 6 mm were installed One of the tubes was placed under the muscle fascia and the other subcutaneously On one side the tubes were embedded in hyaluronic acid before the installation and on the other side in saline The fascia and skin were closed by silk sutures Within the next few days two of the animals showed a marked wound reaction on the saline embedded side and later rejected the implanted tubes The wounds then healed within a few days without suppuration The three animals which did not reject the tubes on the control side showed a marked reaction in the

the vitreous body of the eye after local hyaluronic acid injection. A further observation during the study of joint and tendon disorders was that the subcutaneous part of surgical incisions healed with less connective tissue reaction and adhesion formation.

To investigate whether granulation tissue formation could be diminished and smoother wound healing achieved by installment of hyaluronic acid, the following study was performed.

METHOD

The hyaluronic acid used in this work was prepared from human umbilical cords or rooster combs and sterilized in our laboratory according to Balazs & Sweeney (1968) and Swann (1968). The protein content varied from 1–2 per cent in the first preparation to 0.2–0.3 per cent in the latest preparation, and the molecular weight was 1.3×10^6. The sodium salt of hyaluronic acid was dissolved in a concentration of 5–9 mg per ml in physiological saline. 1–2 ml of this solution was used in the experiments.

In order to investigate the effect of the installation of hyaluronic acid on the subcutaneous scar formation after surgical incision, 45 animals were subjected to 4 cm long incisions symmetrically on both sides of the body, reaching down to the muscular fascia. The fascia was traumatized by 10 strokes of a gauze pad. It was considered to be of great importance that exactly the same damage was performed on both sides of the same animal. Twenty-five rabbits, 10 owl monkeys, and 10 guinea pigs, altogether 45 animals, were used. On one side hyaluronic acid was installed before the wound was closed, on the other side, the control side, saline was injected in two cases. As the injection of saline alone may be harmful to the connective tissue, this procedure was avoided in most animals. The surgical procedure was identical on both sides. Three to six weeks after the operation the animals were sacrificed and the subcutaneous part of the scar explored. The result was evaluated by comparing the reactions of both sides of the same animal. On each side, however, the amount of reaction was classified in three grades. Grade 1 was used if the adhesions formed were thin and sparse and easily broken. Grade 2 included a more dense adhesion formation which was easily disrupted on dissection. The reaction was classified as Grade 3 if the adhesions formed a dense tissue and a knife was necessary for the dissection. One of the animals died in connection with the operation and 5 developed infection; these were excluded from this study.

RESULTS

Of the 39 animals remaining for evaluation, 32 showed less connective tissue reaction with a smoother subcutaneous scar on the hyaluronic acid treated side, 6 showed no difference between the two sides, and in one case the control side had the smoothest healing (Table 1).

Of the 10 owl monkeys two were excluded due to infection. In six of the monkeys the hyaluronic acid treated side was classified as

after about 48 hours and this reaction is not connected with any clinical sign of inflammation (Rydell et al 1969)

From this work it seems that the installation of hyaluronic acid preparation is important in preventing undesired fibrotic reactions in burns tendon injuries and after implantation of foreign bodies as well as in treatment of certain joint disorders

SUMMARY

Injections of hyaluronic acid in 39 animals showed decreased fibrotic wound reactions in 32 cases A decrease in granulation tissue formation was observed as well as diminished formation of adhesions In 9 animals submitted to implants of foreign bodies the tissue reaction was significantly less if the implants were embedded in hyaluronic acid This effect may be explained by the gel like consistency of hyaluronic acid solutions and by the influx of macrophages which occurs after these injections The latter mechanism is suggested to be the most important

Hyaluronic acid application seems to be indicated especially after tendon damage burns and implants of foreign material but also whenever a smooth scar formation is important

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wound area on this side and a large mass of granulated tissue could be palpated. The tubes embedded in hyaluronic acid did not cause any inflammatory reaction and in all animals the wound healed nicely within a few days. Six weeks after the operation the animals were sacrificed and the subcutaneous wound area explored. On the hyaluronic acid treated side only minor tissue reaction was observed with a few weak adhesions. The polyethylene tubes were surrounded by a thin soft capsule which was removed for pathological examination. On the control side a more extensive tissue reaction was observed in all 5 cases with a more marked adhesion formation. In the 3 animals which did not reject the tubes a thick capsule was formed around the tubes. This was removed for pathological examination. The microscopic picture of the capsules showed fewer cells and more fibrous tissue on the control side compared to the hyaluronic acid treated side.

DISCUSSION

Installation of hyaluronic acid subcutaneously seems to delay and decrease granulation tissue formation and fibrosis. Out of 39 animals such an effect was observed in 32 cases.

In a recent study of the healing of skin burns preliminary results show a marked decrease in fibrosis if the wound is treated with hyaluronic acid.

In a study of tendon injuries on rabbits (Rydell 1969) it was shown that installation of hyaluronic acid around the tendon in connection with the injury significantly decreased the formation of adhesions. In a study of hyaluronic acid injections and fracture healing no change in the healing was observed (Rydell 1969).

The cause of the decrease in connective tissue reaction to injuries and implantation of foreign bodies after installation of hyaluronic acid is not known. Hyaluronic acid seems to have a macrophage calling effect when injected into a joint or into the vitreous body of the eye. It would probably have the same effect if injected subcutaneously. At the same time a hyaluronic acid preparation has a gel like composition and could mechanically prevent the ingrowth of tissue. Which of the two factors, the macrophage invasion or the mechanical barrier, is the more important in decreasing the formation of granulation tissue is debatable but probably the invasion of macrophages is more significant. It should be noted that the influx of macrophages into joints after hyaluronic acid injection occurs after 4 hours and disappears

after about 48 hours and this reaction is not connected with any clinical sign of inflammation (Rydell et al 1969)

From this work it seems that the installation of hyaluronic acid preparation is important in preventing undesired fibrotic reactions in burns tendon injuries and after implantation of foreign bodies as well as in treatment of certain joint disorders

SUMMARY

Injections of hyaluronic acid in 39 animals showed decreased fibrotic wound reactions in 32 cases A decrease in granulation tissue formation was observed as well as diminished formation of adhesions In 5 animals submitted to implants of foreign bodies the tissue reaction was significantly less if the implants were embedded in hyaluronic acid This effect may be explained by the gel like consistency of hyaluronic acid solutions and by the influx of macrophages which occurs after these injections The latter mechanism is suggested to be the most important

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ANTERIOR CERVICAL FUSION FOR CERVICAL RHIZOPATHIES

A Follow-up Study

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Cervical rhizopathies are very painful and often protracted conditions which as a rule will improve with conservative treatment. However, cases are quite often found where this treatment does not help and operation is thus indicated. Several types of operations have been described, e.g. decompression of one or more of the nerve roots (Frykholm 1951), evacuation of the intervertebral discs (Hult 1958, Hirsch 1961, Hirsch et al. 1964) and anterior fusions (Cloward 1959, 1963, Robinson et al. 1962, Robinson 1963). No matter which of these methods are used, the pre-operative decision is often difficult for the surgeon. This is usually because of overlapping of the neurological segments in the hand and the arm, making it difficult to determine which level of the cervical spine should be operated on, as well as because of the varying results seen with patients for whom the initial symptoms were similar.

Even with a thorough neurological examination, electromyographic studies, discogram and cervical phlebography—localization of the correct level for operative intervention is not always certain (Robinson et al. 1962, Hirsch et al. 1964, Holt 1964). The best method of localization, as reported by Hirsch (1964), is myelography with positive contrast, a method not presently permitted in Sweden.

In this investigation the level of operation has been determined by a combination of roentgenographical findings and radiating pains in hand and fingers. The operation method described by Cloward (1959) has been used.



Figure 1 A P view of cervical spine with hole and bone plug

MATERIAL

Only th se patient fulfilling the following criteria were operated
1 F ilure to achieve prol nged benef cial results after at least three months of nservative treatment (traction collar X ray treatment et cetera)
2 Signs of degenerative changes on radiographic examination of the cervical pine in no m re than one intervertebral disc at the specific level
3 The presen e of d stinct pa n radiat ng from the cervical reg on to the fingers rr ponding to the nerve root of the degenerated disc (the disc between C5 and C6 c rre po ds to the fir t and second finger the disc between C6 and C7 cor re ponds t the second third and fourth finger and the disc between C7 and T1 rr spond to the fourth and f fth finge) Those patients with diffuse pains in the cervical houlder and arm region or with humeroscapular periarthritis were n t pe at l The operati n itself w s perf rmed on the degenerated disc

Twenty three operations were perf rmed on twenty patients (Table 1) Two p tients requir d r peat operation because of recurrence at a second level and one p ti nt becau e the fir t ope ation ga e no improvement. The patients ranged in age f m 27 t 61 y r with all but two being older than 40 years (27 and 37 year) The duration of the pain pri r to operati n var ed between six months and f year All p tient wer f ll wed up both clinically and radiographically an l demo tr ted a healed f sion at the operated level (Figure 3) The chief point



Figure 2 Lateral view of cervical spine with hole and bone plug The plug has been countersunk a few millimetres

stressed in both the pre operative and follow up examination was whether the patient experienced pain and if he did the types and localization of the pain In addition patients were evaluated with respect to neurological symptoms as well as diminished or painful mobility of the neck and joints of the upper extremity Only one patient (No 13 in Table 1) demonstrated positive findings using the latter criteria

METHOD OF OPERATION

The anterior surgical approach as described by Southwick & Robinson (1957) was used and the fusion was performed according to a modification of the Cloward technique (1959) An opening was made in the mid line over the disc and the adjacent two vertebral bodies with a 10 mm drill borer (Figure 1) Most of the disc substance was evacuated by this procedure The opening was carried down to the



Figure 3 Healed fusion eighteen months after operat on

I rsal cortex of the vertel ral bodies then making it easy to evacuate the disc com pletel with a cone tom No attempt as made to remove any osteophyte With a peci l l rer a l ne plug was taken from the iliac crest and immediately fitted int th ening in th cervical pine The plug was in erted approximately 1 t ? mm deep into the h le so that it c uld not easily be loosened (Figure 2) I t peratively a felt collar was placed around the neck with bed rest for one day The patient was dis harged from the hospital four to five d ys subsequent to u gery

RESULTS

T ible 1 illustrates the patient material and the results of the follow up Of the twenty patients studied two (Nos 1 and 2) were entirely pain free ten were considerably improved but had slight remaining pains

Table 1

Patient	Immediate results	Results of re-examination	Age	Male = M Female = F	Level of operation	Duration of preoperative pains (mths)	Postop. observation time (mths)	Remarks
1	+	1	52	M	C5–C6	48	24	
2	+	1	44	M	C5–C6	7	4	
3	+	(1)	50	M	C6–C7	12	42	Reop. after 4½ years because of recurrence at another level
–	+	–	55	M	C7–Th1	6	1	
4	+	2	27	F	C6 C7	15	17	
5	+	2	17	F	C6 C7	7	18	
6	+	2	48	M	C6–C7	24	11	
7	+	2	42	F	C5–C6	9	10	
8	+	2	44	F	C6–C7	15	24	
9	+	2	44	M	C5–C6	12	18	
10	+	2	59	F	C5–C6	60	8	
11	+	2	53	M	C6–C7/C7–Th1	8	3	
12	+	2	61	M	C5 C6	5	5	
13	—	3	58	M	C6–C7	24	5	Mobility of the neck diminished to about half normal because of pain
14	—	3	37	F	C7–Th1	2½	18	
15	—	4	44	F	C6–C7	10	24	
16		4	44	M	C4–C5/C6–C7	38	78	
17	+	4	52	F	C6–C7	10	24	
–	+	4	54	F	C7–Th1	7	5	Reop. because of recurrence at another level after 1½ years
18	–	4	48	F	C6 C7	48	3	
19	–	4	39	M	C6–C7	42	18	
20	?	4	50	M	C6–C7	10	22	
–	?	?	50	M	C –C6	6	18	Reop. because of no improvement within 4 mths after the first operation

+ Improved within one week postoperatively — Not improved within one week postoperatively

† 1 Complete improvement 2 Considerable improvement—in full work 3 Slight improvement—cannot work 4 No improvement

Table 2 Anatomical localization of the pain
(23 operations)

	Preoperatively	Postoperatively
Skull fingers	2	2
Neck-fingers	19	10
Neck/shoulder-hand/finger	2	2
Neck	–	7
No pains	–	2
	23	23

two patients had slight improvement and five had no improvement at all

One patient (No 3) was pain free for four and one half years subsequent to operation but a few weeks prior to re examination he was operated on because of recurrence at another level The patients with complete improvement and considerable improvement were all at full work and had not sought medical advice for the mild pains they experienced

No correlation was found between the results of operation the age of the patient the preoperative duration of the pains the time of observation after operation and the level of the operation

Several of the patients reported considerable relief of pain during the first few postoperative days (Table 1 Column 2) These were the patients that displayed the best long term results In patients where there was no immediate postoperative relief of pain the long term results were not so good This observation seems to demonstrate that positive results are dependent on the operation and not on the tendency towards slow spontaneous healing often shown by the cervical rhizopathies

In Table 2 several cases are illustrated with complete relief from pain in the hand and arm Some pain in the neck still remained but not so severe as before surgery Similar results are found in operations for herniated lumbar discs where sciatic pains disappear but the patient still has lumbar pain In addition two cases are shown where localization of the pain in the neck shoulder and hand fingers has been difficult to judge

The operation has not only changed the anatomical localization of the pain but also the type of the pain itself Pre operative pains have

usually been severe and prolonged, sometimes continuous. Postoperatively, the pains have occurred intermittently for shorter durations and without the same degree of intensity as pre-operatively.

As the observation time postoperatively is short, we still can expect isolated recurrences in the group of good results. Because of the differences in the patient material it is difficult to compare the results of this investigation with the results published by Hirsch, Holt, Robinson and Cloward. In all of these investigations there are several patients with more diffuse subjective symptoms difficult to evaluate and with multiple disc degenerations in the cervical spine. Even taking these differences into consideration, no conspicuous differences can be found.

When one considers this operation as clearly improving half of the patient group and the fact that the operation is technically simple and well tolerated by the patient, this procedure is clearly justified for those patients in which conservative treatment has failed and no other treatment is available.

SUMMARY

Anterior cervical fusions according to a modification of the Cloward procedure have been performed on twenty patients with isolated degenerative cervical discs. The patients were re-examined three to seventy-eight months postoperatively. Twelve were considerably improved and had returned to full work.

Patients with lasting postoperative relief of pain all reported a clear improvement already within a few days post operation. Patients without any lasting postoperative relief of pain as a rule did not report any improvement at all after the operation.

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FRACTURES OF RADIAL HEAD AND THEIR TREATMENT

GEORG BAKALIM

Received 12.xi.69

During the last two decades it has become usual to treat undislocated radial head fractures conservatively and severely comminuted dislocated fractures surgically by excision of the head of the radius. In addition, early active motion has been used in the treatment. The attitude to fractures of the head of the radius seems to have been significantly influenced by Böhler (1951), who recommended excision when the fragment is larger than one third of the radial head. Charnley (1961), on the other hand, advocated conservative treatment if there is the slightest doubt concerning the therapy. The importance of early mobilization was emphasized by Neuwirth (1942), Mason & Shutkin (1943), Charnley (1961) and Adler & Shaftan (1963). On the other hand, Radin & Riseborough (1966) found that early mobilization may cause dislocation and clearly poorer end results in those cases in which the fragment constitutes half of the radial head and was not initially dislocated.

Prompt excision of the head of the radius in comminuted cases was advocated by Hitzrooth (1912), Cutler (1926), Bohrer (1933), Carstam (1951), Castberg & Thing (1953), Mason (1954) and Arner, Ekengren & Schreeb (1957). Removal of a fragment was considered sound therapy by Carstam (1951) and Arner, Ekengren & Schreeb (1957), while this method was strongly rejected by Murray (1940), Watson-Jones (1955), Wagner (1955) and Charnley (1961). In children it seems advisable not to remove the head of the radius since growth disturbances are likely to result (Murray 1940, Roosvall 1941, Böhler 1951, Carstam 1951, Watson-Jones 1955, Blount 1955).

It should be mentioned that comminution is often worse than the radiograph reveals (Watson-Jones 1955, Wagner 1955, Charnley 1961). In addition, Watson-Jones drew attention to the possibility of fracture

of the capitellum responsible for later extension flexion deficiency and the possible presence of a rupture of the capsule at the ulnar aspect Charnley (1961) too discussed the possible role of ruptures of the collateral ligament and capsule in the development of extension deficiency while he believed that pro-supination deficiency results from injury of the radial head Changes as described above were observed by Arvidsson & Johansson (1955) in arthrographies of radial head fractures Quigley (1949) recommended aspiration as an initial measure and prompt excision if after the puncture limitation of motion and crepitation are observed in connection with passive motion However late excision of the radial head is not recommended in the literature owing to poor results (Hitzrot 1912 Murray 1940)

Attention has been attached to the secondary changes that may occur in the wrist following excision of the radial head Shortening of the radius may cause subluxation of the ulna (Brockman 1930 Lewis & Thibodeau 1937 Dougall & White 1957 Taylor & Connor 1964) Curr & Coe (1946) were the first to describe a case in which subluxation of the distal head of the ulna was primarily present in connection with fracture of the radial head In 1951 Essex Lopresti described two such cases

As is shown in the foregoing there is considerable diversity of opinion concerning the therapy Although conservative treatment and early mobilization have become widely adopted at least in borderline cases it still seems uncertain whether conservative or surgical treatment is the best The effect of the duration of immobilization on the results of treatment has not been analysed The occurrence of dislocation in connection with early mobilization and its significance are other points which seemed to deserve closer study

MATERIAL

The series consists of patients with fracture of the head of the radius treated at the Clinic for Orthopaedics and Traumatology during the period 1961 1965 Follow up examinations were attended by 209 patients i e 130 women and 64 men There were 4 patients who belonged to the group of children during the time of treatment, although the epiphyseal line was already closed. Epiphyseolysis was observed in 11 children

The age of the patients ranged from 5 to 78 years 6 2 per cent of patients were under 15 years old, 17 2 per cent 15–24 years old 72 3 per cent 25–64 and 4.3 per cent over 65 Females outnumbered males 2 to 1 The radial head was fractured in 55 per cent the left radial head in 45 per cent. There were no obvious sex differences

(41)
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Received 19 xi 69

During the last two decades it has become usual to treat undislocated radial head fractures conservatively and severely comminuted dislocated fractures surgically by excision of the head of the radius. In addition, early active motion has been used in the treatment. The attitude to fractures of the head of the radius seems to have been significantly influenced by *Böhler* (1951), who recommended excision when the fragment is larger than one third of the radial head. *Charnley* (1961), on the other hand, advocated conservative treatment if there is the slightest doubt concerning the therapy. The importance of early mobilization was emphasized by *Neuwirth* (1942), *Mason & Shutkin* (1943), *Charnley* (1961) and *Adler & Shafton* (1963). On the other hand, *Radin & Riseborough* (1966) found that early mobilization may cause dislocation and clearly poorer end results in those cases in which the fragment constitutes half of the radial head and was not initially dislocated.

Prompt excision of the head of the radius in comminuted cases was advocated by *Hitzroth* (1912), *Cutler* (1926), *Bohrer* (1933), *Carstam* (1951), *Castberg & Thing* (1953), *Mason* (1954) and *Arner, Ekengren & Schreeb* (1957). Removal of a fragment was considered sound therapy by *Carstam* (1951) and *Arner, Ekengren & Schreeb* (1957), while this method was strongly rejected by *Murray* (1940), *Watson Jones* (1955), *Wagner* (1955) and *Charnley* (1961). In children it seems advisable not to remove the head of the radius, since growth disturbances are likely to result (*Murray* 1940, *Roosvall* 1941, *Böhler* 1951, *Carstam* 1951, *Watson Jones* 1955, *Blount* 1955).

It should be mentioned that comminution is often worse than the radiograph reveals (*Watson Jones* 1955, *Wagner* 1955, *Charnley* 1961). In addition, *Watson Jones* drew attention to the possibility of fracture

Table 2 Methods of treatment in the present series

Adults	Type of fracture	Treatment	Number	
Adults	I	Conservative	90	149
	II		59	
	II	Excision of radial head	8	16
	III		8	
	I	Removal of fragment	1	2
	II		1	
	II	Late excision of radial head	1	2
	III		1	
		Multiple injuries in elbow joint		
	II	Conservative	16	25
	II	Excision of radial head	4	
	III		5	
Children	I	Conservative	2	15
	II		2	
	Epiphyseolysis		6	
	Epiphyseolysis	Open reduction	5	
Total			209	

The epiphyseal line closed

results of the radial head fractures and were consequently considered as a separate group The concurrent injuries are listed in Table 1

TREATMENT

Table 2 shows the distribution of the series by type of treatment The treatment was predominantly conservative and included early mobilization The 90 patients with fracture of degree I were always those 59 with fracture of degree II usually conservatively *treated* Excision of the head of the radius was performed in 8 cases in group II All patients in group III were surgically treated Late excision after two to three months was performed in 2 cases *In the* 25 cases in which a fracture of the radial head was treated in connection with the treatment of concurrent injuries in the elbow joint the procedures carried out included reduction of luxations osteosynthesis etc The head of the radius was excised in 9 *instances* and conservatively treated in 16 The duration of immobilization was often longer than in the cases

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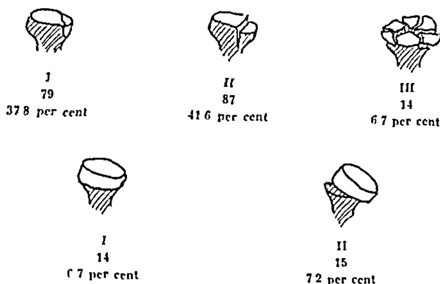


Figure 1 Classification of the fractures of the radial head by degree of severity I No dislocation II Dislocated III Comminuted

The distribution of the various types and classifications of fractures are shown in Figure 1 As regards the size of the fragment in the majority of cases the latter was ⅓ or ¼ of the radial head A fragment size of ⅔ or $^1/_1$ was infrequent The last subgroup consists of cases in which the fracture was in the neck of the radius (in children epiphyseolysis)

Twenty five patients showed a total of 31 concurrent fractures or dislocations (29 in the elbow joint and 2 Colles fractures) which may have influenced the end

Table 1 A total of 31 concurrent injuries possibly influencing the end results in 25 patients with fracture of the radial head

Colles fracture of radius	2
Fracture of ulna	2
Fracture of olecranon	2
Fracture of coronoid process	6
Fracture of capitellum	2
Fracture of lateral humeral condyl	3
Fracture of lateral humeral epicondyl	2
Fracture of medial humeral epicondyl	2
Dislocation of elbow joint	10
Total	31

Table 4 Fractures of degree II (dislocation) Conservative treatment

Estimation of the results	1/	1/	$^{2}/_{3}$	$^{1}/_{1}$	Total	%
Good	27	15	2	2	47	79 7
Fair	7	0	2	1	9	15 2
Poor	1	1	1	0	3	5 1
Total	35	16	5	3	59	100 0

Table 5 shows the results in the subgroup with a fragment size of ⅓ of the radial head Immediate or early mobilization was used in 14 cases Seven of these patients were treated entirely without an arm sling while in the remainder the arm sling was used for one week but was removed every day to enable motion therapy As may be seen in the Table dislocation was observed after immediate or early mobilization in $^{5}/_{1}$ cases after two to four weeks immobilization in $^{3}/_{11}$ patients The results in the group with a fragment size of ½ of the radial head and no primary dislocation are shown in Table 8 among the patients treated by immediate or early mobilization $^{2}/_{8}$ showed dislocation / cases dislocated after one week s treatment with a plaster case and $^{11}/$ after three to five weeks The various groups are small but the results show the same trend irrespectively of whether the fragment

Table 5 Effect of method and duration of immobilization on secondary dislocation Initially no dislocation was present and the fragment was ⅓ of the radial head

No of cases (no dislocation)	Immobilization Method	Time (weeks)	Secondary dislocation (radiological evidence)		Clinical results Good	Fair	Poor
14	Arm sling	0–1	−	9	8	1	0
			+	5	4	1	0
12	Plaster cast	1	−	10	8	2	0
			+	2	2	0	0
11	Plaster cast	–4	−	8	8	0	0
			+	3	3	0	0
37				37	33	4	0

Table 3 Fractures of degree I (no dislocation) Conservative treatment

Estimation of the results	1/3	1/2	/3	1/1	Total	%
Good	*33*	*25*	*1*	*9*	*68*	*75 6*
Fair	2	10	1	4	17	18 9
Poor	2	2	0	1	5	5 5
Total	37	37	2	14	90	100 0

showing radial head fractures alone and was dependent on the concurrent injury

As regards the epiphyseolytic fractures in children the line of treatment was conservative a first attempt always being made with closed reduction Six patients were treated conservatively 5 operatively

The results were regarded as good if there was no pain and limitation of movement was a maximum of 10 degrees in one direction fair *if there was occasional pain or limitation of movement by 10 to 30* degrees in one direction poor if there was continuous pain or limitation of movement by more than 30 degrees Radiographs were not taken into account in the clinical evaluation since the clinical results may be better than the radiograph suggests

Conservative Treatment

The clinical results in the group with fracture of degree I are shown in Table 3 The results were somewhat poorer in subgroup ½ than in subgroup ⅓ Table 4 shows the results in those patients with fracture of degree II who were conservatively treated *The results were better* in subgroup ½ than in subgroup ⅓

The results showed no correlation to age The distribution over the different age groups was very even

In addition the effect of the method and duration of immobilization on the results of treatment was analysed in group I in the subgroups in which the fragment size was ⅓ and ½ of the radial head As already mentioned it has been stated in the literature that early active motion therapy may cause secondary *dislocation if the fragment is* ½ of the radial head For this reason the results in the two subgroups in question are analysed separately

Table 6. Effect of method and duration of immobilization on secondary dislocation. Initially no dislocation was present and the fragment was ¼ of the radial head

No of cases (no dislocation)	Immobilization Method	Immobilization Time (weeks)	Secondary dislocation (radiological evidence)		Clinical results Good	Fair	Poor
8	Arm sling	0–1	−	5	3	2	0
			+	3	3	0	0
9	Plaster cast	1	−	7	6	1	0
			+	2	1	1	0
20	Plaster cast	2–5	−	9	7	1	1
			+	11	5	4	2
37				37	25	9	3

was ⅓ or ½. The tendency towards dislocation seems to be greater when early mobilization are used. The lowest frequency of dislocation was noted after one week's immobilization in a plaster cast. These observations apply only to the radiological state. The clinical results were not impaired owing to secondary dislocation. There were no poor results in those cases in which the fragment constituted ⅓ of the radial head and only 2 poor in the group with a fragment size of ½.

In group II $^{19}/_{39}$ primary dislocations disappeared and showed correct position at the follow up examination.

Excision of the Radial Head

The head of the radius was excised in 25 cases but only 16 of these showed radial head fractures alone. Nine patients had other concurrent injuries and fractures of the elbow. These cases are considered separately.

Excision of the radial head is mainly performed in order to prevent limitation of pro-supination when there is a risk of adhesion of the fragments to the annular ligament. In the group of 16 patients showing fracture of the radial head alone there was no limitation of pro-supination in 7, whereas a deficiency in pro-supination by 20 degrees was present in 4, deficiency by 30 degrees in 2, and by 40, 70, and 80 degrees in 3. These cases cannot however be compared to the conservatively treated ones because of the difference in severity of the fractures. Among those patients who had other injuries in the elbow joint only

one showed complete pro-supination as an end result The remaining 8 showed limitation by 10 to 95 degrees These results bore a correlation to the concurrent fracture and the total injury

There is a question as to whether a sufficient portion of the radial head had been removed and as to whether the end results were influenced by this factor According to the radiographical evidence excision was not sufficiently extensive in $^{3}/_{14}$ cases In these the end result was fair there remained a limitation of pro-supination by 20 30 and 30 degrees respectively Among those who had had a sufficiently extensive operation 7 showed complete pro-supination while 3 had a limitation by 20 degrees and a further 3 had a deficiency of 40 70 and 80 degrees respectively

Complications Due to Excision of the Radial Head

Radio-ulnar subluxation is a complication much discussed in the literature In the present series it was encountered in 3 instances after excision of the radial head in cases showing fracture of this structure alone and in 3 operatively treated cases in the group with fracture of the radial head concurrent with other injuries in the elbow joint The displacement ranged from 3–5 mm In all of the cases the trauma was rather violent Two patient showed luxation of the antebrachium and one a fracture of the coronoid process The type of fracture of the radial head does not seem to be decisive Subjectively there was nothing abnormal in the wrist All these patients showed normal motion of the carpus

Radio-ulnar synostosis was encountered in two patients one of them after partial excision of the radial head Apparently a lesion of the interosseous membrane and haematoma were the cause Valgus position has been mentioned in the literature but in the present series there was only one such case a patient showing 15 degrees worse valgus position on the operated side Nearthrosis of the ulna was observed in one patient In connection with excision of the radial head a small marginal protuberance had remained which had later become articulated Secondary osteoarthritis was observed in only two patients who had sustained very severe multiple injuries of the elbow joint None of the patients showed myositis ossificans

The clinical results in the 16 cases of fracture of the radial head alone are shown in Table 7 the fracture was of degree II in 8 cases of degree III in 8 cases The size of the fragment appears in the Table

Table 7 Cases of fracture of degrees II and III in which the head of the radius was excised

Estimation of the results	1/3	1/4	2/3	1/1	III	Total
Good	2	1	0	0	3	6
Fair	1	1	0	0	4	6
Poor	2	1	0	0	1	4
Total	5	3	0	0	8	16

The groups are small and no conclusions can be drawn concerning the factors responsible for the poor results. It should be born in mind however that the operatively treated fractures as a rule were more severe than the conservatively treated injuries of the same degree. The fragment was larger and dislocation worse.

The results in those 9 cases in which fracture of the radial head was concurrent with other injuries in the elbow joint are shown in Table 8. Since the latter injuries were often more significant and required separate operative procedures, the results cannot be considered representative for fractures of the radial head. The end results were in part dependent on the concurrent injury which sometimes was extensive damage to the joint involving soft tissue lesions and rupture of the capsule and ligament with intra and extra articular haematomas. The results were clearly poorer than in the group with radial head fracture alone treated by excision of the radial head.

Table 8 Results of treatment after excision of the head of the radius in cases showing fracture of the radial head and concurrent injuries in the elbow

Estimation of the results	1/3	1/4	2/3	1/1	III	Total
Good	1	1	0	0	0	2
Fair	0	0	0	0	0	0
Poor	1	0	0	1	5	7
Total	2	1	0	1	5	9

Fractures in Children

This group consists of patients in whom the epiphyseal line was still open Age as such was not a criterion since there is wide variation in regard to the age at which the epiphyseal line closes In planning the treatment it is very important to consider the risk of growth disturbances Six patients on whom closed reduction was performed were followed up The result was good in 4 cases fair in 1 and poor in 1 In 4 cases surgical reduction was performed after unsuccessful closed reduction In these cases the results were good in 1 fair in 1 and poor in 2 In addition there was one patient who showed dislocated fracture of the head of the radius Operative reduction was performed and the annular ligament was sutured The clinical result was good

DISCUSSION AND CONCLUSIONS

The results of conservative treatment were very good The results of operative treatment were not equally good but it should be borne in mind that the fractures which were operatively treated were severe dislocation and comminution being worse than in the conservatively treated cases They were clearly not comparable The immobilization time after excision of the radial head was in some cases unnecessarily long The results showed no correlation to the immobilization time

The tendency towards dislocation seems to be greater when early mobilization is used in fractures of degree I The observations seem to indicate that one week s immobilization in a plaster cast is the best method of preventing secondary dislocation in the treatment of fractures in which the fragment is ⅓ or ½ of the radial head The number of cases with a fragment size of ⅔ of the radial head was too small to allow of any conclusions and no patient with fracture of the neck of the radius was treated by immediate mobilization The clinical results showed no clear correlation to the use of immediate or early mobilization nor to the use of a short or long period of immobilization The clinical results were not impaired owing to secondary dislocation by early mobilization in fractures of degree I contrary to Radin & Riseborough (1964)

In explanation of the good results after one week s immobilization in a plaster cast and the more pronounced tendency towards dislocation after more protracted plaster cast immobilization it may perhaps be suggested that when complete bony union has not yet occurred active motion therapy of the elbow joint may force the fragments to settle in

Table 7 Cases of fracture of degrees II and III in which the head of the radius was excised

Estimation of the results	1/3	1/	2/3	1/2	III	Total
Good	2	1	0	0	3	6
Fair	1	1	0	0	4	6
Poor	2	1	0	0	1	4
Total	5	3	0	0	8	16

The groups are small and no conclusions can be drawn concerning the factors responsible for the poor results It should be born in mind however that the operatively treated fractures as a rule were more severe than the conservatively treated injuries of the same degree The fragment was larger and dislocation worse

The results in those 9 cases in which fracture of the radial head was concurrent with other injuries in the elbow joint are shown in Table 8 Since the latter injuries were often more significant and required separate operative procedures the results cannot be considered representative for fractures of the radial head The end results were in part dependent on the concurrent injury which sometimes was extensive damage to the joint involving soft tissue lesions and rupture of the capsule and ligament with intra and extra articular haematomas The results were clearly poorer than in the group with radial head fracture alone treated by excision of the radial head

Table 8 Results of treatment after excision of the head of the radius in cases showing fracture of the radial head and concurrent injuries in the elbow

Estimation of the results	1/	1/	2/3	1/	III	Total
Good	1	1	0	0	0	2
Fair	0	0	0	0	0	0
Poor	1	0	0	1	5	7
Total	2	1	0	1	5	9

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the correct position especially if it is instituted after a week when a wrapping has formed. In some cases the fractured head of the radius moves inside a smooth, intact annular ligament. It may explain the disappearance of 19 primary dislocations in 59 cases of degree II. The view pronounced above concerning the role of active mobilization applies sometimes in fractures in other connections as well.

The results of this study seem to indicate that conservative treatment is justified in most cases of radial head fracture. Operative treatment seems to be indicated only in fractures with severe comminution. Most fractures of degree II can be successfully treated by conservative methods, but in the absence of a material for comparison it cannot be stated that cases with a marked dislocation of the fragment should be so treated.

The results of treatment were clearly impaired by the presence of concurrent injuries in the elbow joint. Such cases have caused confusion in many reports previously.

The results showed no correlation to age.

The few complications after excision of the radial head did not generally influence the end results.

SUMMARY

The series consists of 209 patients with fracture of the radial head treated at the Clinic for Orthopaedics and Traumatology during the years 1961–1965. The treatment was predominantly conservative. Active motion therapy was commenced early. The effect of the duration of immobilization on the results of treatment is discussed. The clinical results showed no clear correlation to the use of a short or long period of immobilization. The observations seem to indicate that one week's immobilization in a plaster cast is the best method for preventing secondary dislocation. On the other hand the clinical results were not impaired owing to the occurrence of secondary dislocation after early mobilization. Conservative treatment seemed justified in most cases of radial head fractures. Excision of the radial head was indicated only in fractures with severe comminution.

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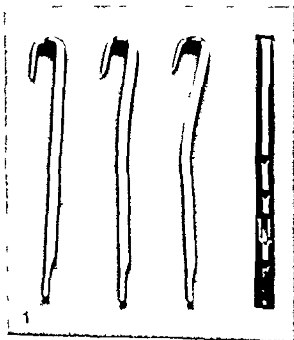


Figure 1 The new compression plate

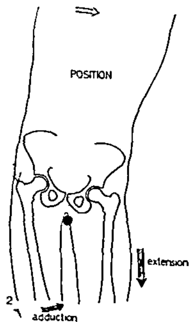


Figure 2 Position

Acta orthop Scandinav 41 332–340 1970

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A NEW COMPRESSION PLATE FOR HIGH FEMORAL OSTEOTOMY FOR OSTEOARTHRITIS OF THE HIP

Preliminary Report

GORAN WIDOLF

Received 6 ix 69

During the last few years some new nails and plates for high femoral osteotomy have been designed most of them have meant compression between the two bony fragments which must be said to be a great improvement compared with former devices

Figure 1 shows a new compression plate It is 174 mm long and 12 mm wide The head of the plate is bent twice at an angle of 90 degrees and has been given the form of a thin tip The other end of the plate is also given the form of a thin tip but straight Though this tip one hole is drilled and through the stem of the plate four holes Hole number three from the top is oblong Three forms are supplied a straight plate and plates bent at an angle of 10 and 15 degrees just above the top hole It is made in 832 SL an acid fast steel from Avesta Jernverks AB Avesta Sweden Zimmer stainless screws are used to avoid corrosion

OPERATION

The patient lies supine on an orthopaedic table Figure 2 The leg to be operated upon is slightly adduced the other leg is extended and the upper part of the body is bent slightly away from the operation side This causes the greater trochanter to protude and facilitates insertion of the plate The skin is incised laterally in the usual way but the incision passes proximately by the greater trochanter half way to the iliac crest The upper end of the shaft of the femur is exposed in the usual way The gluteal muscles are divided longitudinally and the top of the greater trochanter is made free In a simple osteotomy a plate angled 10 or 15 degrees is chosen If a 15 degree plate is chosen the

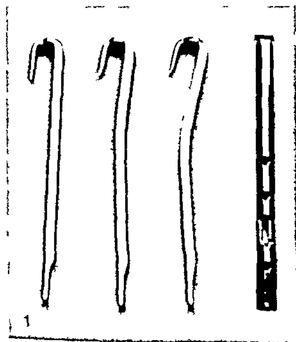


Figure 1 The new compression plate

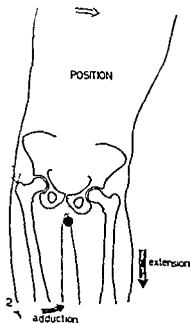
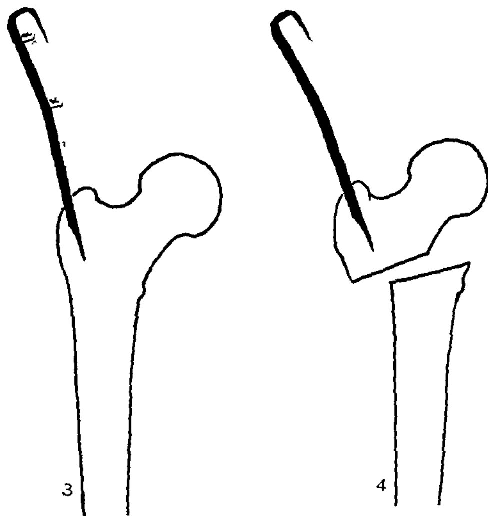


Figure 2 Position

insertion of the tip of the plate must be just lateral to the top of the greater trochanter so that the direction of the tip of the plate makes an angle of 15 degrees with the shaft of the femur. The plate is inserted 3–4 cm to get a firm grip in the desired direction (Figure 3). After this the osteotomy is performed in the usual way. The leg is extended a little to make the fragments free (Figure 4). The plate can now be driven in until the cross piece of the head is pressed against the top of the greater trochanter and the thin tip of the head perforates the cortex at the base of the neck of the femur. The lower tip of the plate is now bent at an angle of 45 degrees with a Rush pin bender (Figure 5) and a screw is driven in through the femur in the distal end of the oblong hole in the stem of the plate so as to adapt but not compress the plate to the shaft of the femur.



Figures 3–7. A simple osteotomy. α = 15 degrees.

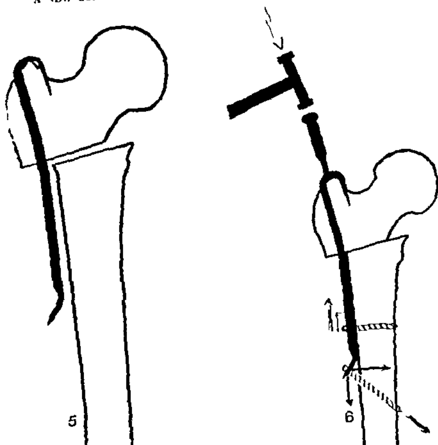
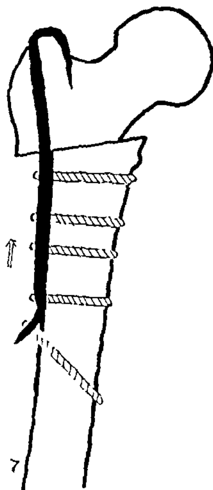


Figure 6 The plate and the two bony fragments are now adapted The first *compression* is achieved by hammering the head of the plate into place The degree of compression can be recorded by the head of the screw which moves proximally in the oblong hole When the tone of the hammer strokes indicates that the two fragments have been compressed the head of the screw in the oblong hole has usually moved 4 5 mm *in a proximal direction indicating the same measure of compression* This done a screw is tightly driven in through the out bent distal tip i e obliquely to the shaft of the femur The hole in the lateral cortex is made wider than the threads of the screw and the hole in the medial cortex of ordinary width The direction of the screw gives the *resulting force* and the arrows indicate the components Figure 6 in this way the final compression is achieved In all the com

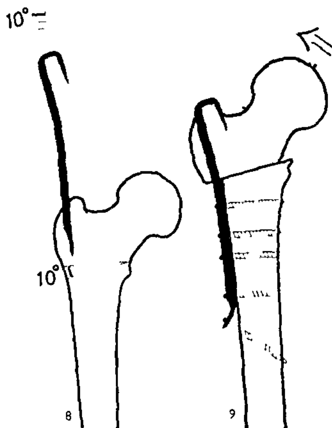
pression usually amounts to 5-8 mm Finally Figure 7 the other screws are driven in

At the top of the greater trochanter the plate perforates the cortex twice This means a firm fixation which prevents rotation and turning into varus displacement between the two fragments



In wedge osteotomies for valgus angulation for example 10 degrees angulation the procedure is as follows A 10 degree plate is chosen The tip of the plate is inserted parallel to the shaft of the femur Figure 8 A wedge of 10 degrees is taken out and the procedure is as above The end result is shown in Figure 9

In wedge osteotomies for varus angulation for example α degrees a straight plate is chosen inserted at an angle of α degrees to the shaft of the femur Figure 10 A wedge of α degrees is taken out according to the Figure The end result is shown in Figure 11

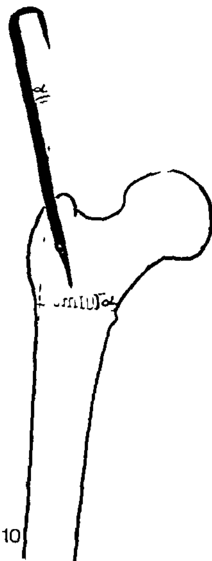


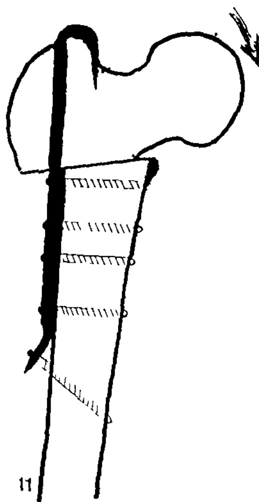
Figures 8 and 9 Valgus angulation

Figure 12 shows an X ray picture of a wedge osteotomy at a varus angulation of 10 degrees immediately after operation Figure 13 shows a simple osteotomy healed

More than 40 patients have now been operated upon In Patient 2 the plate fractured because it was too thin at the beginning After this incident the plate was made heavier and since then no complications have occurred No pseudarthrosis or delayed union has been registrated Furthermore the plate has been used at two operations where the patient had got a pseudarthrosis after osteotomy with other types of plates which did not give compression in the osteotomy Both patients have healed without delay

The postoperative treatment is as follows. On the third day after operation the patient can leave bed and is allowed to load the operated leg with one sixth of the body weight, as the leg equals one sixth of the body weight. As soon as the patient can manoeuvre well on crutches, that is, can easily go to bed and get up, manage stairs without help, he is discharged. This means that a male patient with strong arm muscles and a good wife at home can be discharged 2–3 weeks after the operation, while an older fat woman with weak arms comes home considerably later. It is evident that the physical condition of the pa





Figures 10 and 11 Varus angulation



Figure 12 Varus angulation
Figure 13 A simple osteotomy

tient and his social conditions affect the length of the stay in hospital As soon as bony callus is seen on the X ray film which occurs 4 7 weeks after the operation the patient is allowed to load the leg gradually more When the callus is strong enough—which occurs two to three months after the operation—the patient is trained to walk without sticks with both his arms elevated and his hands clasped above his head The patient is trained to walk equal steps and to load his legs equally This rapidly makes the hip abductors sufficient

The forty patients have been followed three to twelve months A follow up of the group two years after the operation is planned

DISCUSSION

A new compression plate for high femoral osteotomy with the following advantages is described

1 It can be inserted from above in a distal direction which from a purely mechanical point of view is sound when the problem is to compress two fragments

2 No drill jigs or other special instruments are necessary Hammer stamp, screw driver, and Rush pin bender are available at every orthopaedic operation department

3 Varus and valgus angulation can easily be performed

4 Many plates, for example the Tupman and Nissen plates protrude laterally at the greater trochanter and cause pain and other difficulties Often the patient cannot lie on the operated side and the plate has to be extracted The new plate goes through the greater trochanter and cannot cause such trouble

5 The plate gives exact fixation and compression The patient can get out of bed quickly During the first three days in bed the physiotherapist teaches the patient to innervate his quadriceps and to bend his knee The physiotherapist also has an easy job of teaching the patient to walk on crutches

6 The patient is discharged after a few weeks which reduces the costs of hospital stay

7 No X ray exposures are needed during the operation

8 The operation generally takes no more than 30 45 minutes

SUMMARY

A new compression plate made of acid fast steel for high femoral osteotomies is presented It is inserted from above in a distal direction No drill jigs or other special instruments are necessary and no X ray exposures are required during the operation The patient can leave bed on the third day after the operation

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TREATMENT OF FRACTURES OF THE FEMORAL SHAFT

M Blichert Toft & A Hammer

Received 25 iv 69

It has been claimed recently that no fixed principles apply to the treatment of femoral shaft fractures in adults the choice of method depending upon the surgeon s experience and the *armamentarium available* in the hospital (Dencker 1968) Traction is still recommended by most *workers* (Brandberg 1958 Dencker 1965a *Harvey et al* 1968) but internal fixation has gained ground in special types of fracture Most *reports* on this subject—including all those from Denmark (Madsen 1966 Horsnæs 1968 Tophøj & Sorensen 1968)—deal only with the results of one method and/or given types of fracture so that the materials are selected (Kuntscher 1940 Lauritzen 1949 Peterson 1950 Bohler 1951 Aronsson 1956 Palmer 1957 Smith 1964 Horsnæs Tophøj & Sorensen Rokkanen et al 1969) This renders difficult any general assessment of this given type of fracture Only a few have analysed their entire materials (Brandberg Nichols 1963 Dencker 1965a) On this background we felt that the total therapeutic results in fractures of the femoral shaft in adults over a period of 10 years would merit publication in particular as the results differ in several respects from previous reports

MATERIAL

The material comprises 9 patients with 82 fractures of the femoral shaft from the 10-year period October 19 8–October 1968 (Figure 1) The aetiology traumatic in all cases, is specified in Table 1 The classification into types according to Dencker is listed in Table 2 Open fractures were present *in* 22 ca es, making up one quarter of the material 27 82 fracture were components of multiple fractures.

DISCUSSION

A new compression plate for high femoral osteotomy with the following advantages is described

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8 The operation generally takes no more than 30–45 minutes

SUMMARY

A new compression plate made of acid fast steel for high femoral osteotomies is presented It is inserted from above in a distal direction No drill jigs or other special instruments are necessary, and no X ray exposures are required during the operation The patient can leave bed on the third day after the operation

Table 2 Type of 82 fractures of the femoral shaft

Type	Number of fractures		Total
	Closed	Open	
Transverse fracture	17	8	25
Oblique fracture	21	3	24
Comminuted fracture	19	10	29
Double fracture	3	1	4
Total	60	22	82

Table 3 37 fractures of the femoral shaft treated by Küntscher osteosynthesis and 3 treated by the method of Rush (in parentheses)

Intramedullary nailing				
Type of fracture	Level of fracture on the femoral shaft			Total
	Upper third	Middle third	Lower third	
Transverse fracture	–	?2	(2)	24
Oblique fracture	–	6	–	6
Comminut d fracture	–	9	(1)	10
D uble fracture	–	–	–	0
Total	0	37	(3)	40

Clover leaf sh ped Küntscher nails of stainless steel were used. In 31/37 cases the ost o ynthesis w s done immediately. The open method with anterolateral ac ce s by exposing the bone ends and retrograde insertion of the guide was employed. Drilling of the medullary cavity—as described by Küntscher (19 9) and Rokkanen et al (1969)—was n t u ed.

In the con erv tively treated group the standard method was application of a Braun splint and wire traction through the tibial tuberosity

Immedi te osteosynthe is was done in 18/22 open fractures. Chemotherapy was gi en in the form of penicillin and/or streptomycin.

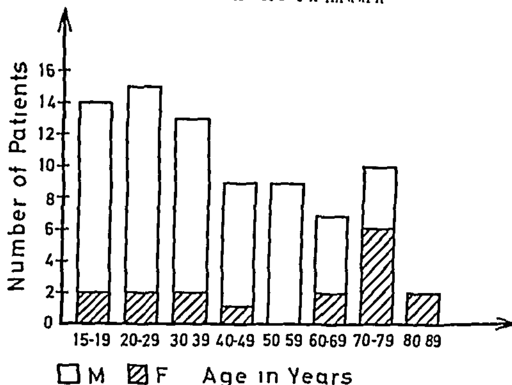


Figure 1 Age distribution and sex ratio 79 patients with fractures of the femoral shaft

Table 1 Distribution of fractures by eliciting cause

Cause	Number of fractures	
	M	F
Traffic accident	53	6
Fall	[illegible]	12
Working accident	6	0
Total	64	18

METHOD

The therapeutic methods in relation to the level and type of fracture are shown in Tables 3 4 and 5 Three patients are not included in this survey Two of them were treated by non weight bearing and the third died of other injuries shortly after the accident

instituted at once. This was followed by walking exercises in the pool and between bars, later with crutches until full weight bearing was allowed at the time of clinical healing. In the conservatively treated group active exercises were started immediately. The traction was maintained until consolidation had taken place and thereafter walking exercises were started as stated above.

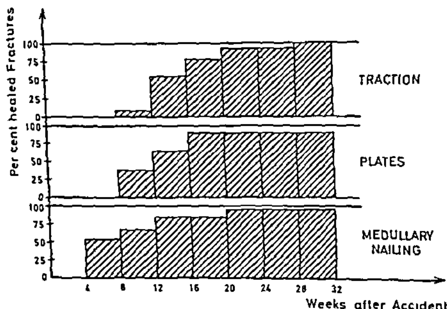


Figure 2. Healing time assessed for 77 fractures (excluding one patient who had amputation, two who died and two treated merely by non weight bearing, a total of 5 fractures)

EARLY RESULTS

Healing Time and Duration of Stay in Hospital

As a criterion of healing the patient had to be able to stand on the leg without pain at the site of fracture which must have become consolidated showing radiological union. By this criterion healing took place within 32 weeks except in three patients. Figure 2 gives the healing time for the three groups of patients.

Among the 27 fractures which were just one component of multiple fractures the time of healing could be assessed in 26. Union had taken place in 20 cases within the 16th week and in all cases by the end of the 24th week.

Table 4 11 fractures of the femoral shaft treated by plate fixation (5 Haggland 1 McLaughlin and 5 sliding plates)

Plate fixation				
Type of fracture	Level of fracture on the femoral shaft			Total
	Upper third	Middle third	Lower third	
Transverse fracture	–	–	1	1
Oblique fracture	1	2	–	3
Comminuted fracture	1	2	3	6
Double fracture	1	–	–	1
Total	3	4	4	11

Table 5 28 fractures of the femoral shaft treated by traction

Traction				
Type of fracture	Level of fracture on the femoral shaft			Total
	Upper third	Middle third	Lower third	
Transverse fracture	–	–	–	0
Oblique fracture	1	4	8	13
Comminuted fracture	2	6	4	12
Double fracture	–	2	1	3
Total	3	12	13	28

POSTOPERATIVE TREATMENT

The group treated by osteosynthesis was gradually mobilized During the first two weeks the limb was elevated on a Braun splint and physical therapy was

Table 7 Postoperative course assessed for 79 fractures in relation to treatment

Treatment	Lethality	Infection	Unstable fixation of fracture	Amputation	Phlebitis	Emboli	Delayed union	Non union	New fracture of the same femur
Medullary nailing	0	0	5	0	2	0	1	1	0
Plating	0	0	2	0	0	1	1	0	0
Traction	0	1	–	0	1	0	0	0	2

Table 8 Late therapeutic result in 65 fractures of the femoral shaft

Treatment	Shortening		Rotation		Angulation		Flexion in knee joint	Atrophy of thigh	
	1-3 cm	> 3 cm	10–20	> 20	10–15	> 15	< 90	1-3 cm	> 3 cm
Medullary nailing	2	0	4	1	0	0	0	2	0
Plating	2	0	1	0	0	0	1	1	1
Traction	7	0	0	1	4	1	0	3	0

Table 9 Classification of late results according to Dencker

Result	Number of fractures			Total
	Medullary nailing	Plating	Traction	
Excellent or good	35	9	19	63
Satisfactory	0	0	1	1
Poor	0	1	0	1
Very poor	0	0	0	0

Table 6 Average duration of stay in hospital stating range

Group of pts	Treatment	No of pts	Days
Patients with isolated fracture	Osteo synthesis	30	61 (16–189)
	Traction	21	116 (90–175)
Patients with multiple fractures	Osteo synthesis	18	109 (34–290)
	Traction	6	

The duration of stay in hospital is apparent from Table 6 Four patients—2 who died and 2 who had fissures— are not listed on this Table

Complications

Table 7 lists the complications occurring in relation to the treatment This Table does not include two patients who died a 33 year-old man with multiple fractures as well as severe injuries to the abdomen and chest who died on the first day and a 78 year old man with severe cardiac and renal failure to which he succumbed on the tenth day High amputation was done in a patient with severance of the femoral artery and a severe crush injury of the leg Because of lack of viability the amputation had to be performed through the femoral fracture These three complications are not ascribed to the fracture or its treatment

LATE RESULTS

Follow up

64 patients with 66 fractures attended follow up in the winter 1968–1969 *The remaining group of 15 patients will be reported in a separate* section The follow up period ranged from 10 to 0 5 years average 5 years All follow up examinations *were performed by the authors* The results are given in Table 8 On the basis of the objective findings and the patients *subjective complaints the therapeutic results were grouped* (Table 9) according to Deneker s classification (Table 10) The patient who underwent femoral *amputation had no complaints* and is not listed in the Tables giving the results of the follow up

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procedure was omitted Later this patient was awarded a disablement pension

Development of Osteoarthritis in the Hip or Knee

In 28 patients under 40 years of age the femoral fracture was an isolated fracture of the lower limb The hip and knee joints were X rayed at follow up In 4 cases—1 hip and 3 knees— *followed for 6 to 9 5 years* unilateral osteoarthritis was demonstrated on the side of the injury The X ray films were compared with the films from the time of the accident when the osteoarthritic changes had not been present All these patients had sustained their femoral fracture by being run over by cars In 2 consolidation had taken place with slight to moderate deformity at the site of the fracture

Socio-economic Status

This analysis comprised 33 working patients—including 5 women—under 60 years with isolated fracture of the femoral shaft In 29 cases the social status was unchanged One had been awarded disablement pension Two had lighter work although they did not have relevant complaints One who had femoral amputation was rehabilitated and thereby obtained a higher social status

The average period of illness was 8½ months (2 24)

The Group Not Included in the Follow-up

This group comprises 15 patients with 16 fractures—one fifth of the entire material All but two who died had been followed in the department until healing took place Eleven fractures healed without deformity and two with a 10–15 varus deformity One developed pseud arthrosis but operation was performed with a favourable result

At the time of follow up 8 of these patients were alive 4 were unable to attend and 4 could not be assessed because of other disabling conditions On inquiry and/or examination none of these 8 patients had complaints that could be attributed to the femoral fracture

DISCUSSION AND CONCLUSION

According to Key (1955) and Palmer (1962) transverse and short oblique fractures through the middle third of the femoral shaft make up the main indication for Kuntscher nailing Aronsson s experience

Table 10 Dencker's classification of late results in treatment of femoral shaft fractures

Result	Excellent or good	Satisfactory	Poor	Very poor
Discomfort	none or slight	moderate	severe	very severe
Shaft shortening	< 3 cm	< 5 cm	< 8 cm	> 8 cm (amputation)
Angulation	< 15	< 20	> 20	no union
Flexion of knee joint	> 90	> 45	< 45	
Instability in knee joint	0	< 10	> 10	
Extension defect in knee joint	none	< 5	> 5	
Thigh atrophy	< 2 cm	< 3 cm	> 3 cm	

The osteosynthesis material was removed only in the group treated by medullary nailing and in these cases at the end of one year

Corrective Procedures

In the course of the follow up period corrective treatment had been given in 8 cases Quadriceps lysis in 3 brisement force of the knee in 2 corrective osteotomy in 1 because of osteoarthritis in the knee due to a 12 varus deformity after the healing of a low femoral shaft fracture In 2 cases operation on a pseudarthrosis was carried out as a link in the treatment of delayed union Four of the 5 patients who developed ankylysis of the knee joint had multiple fractures including fracture of the homolateral lower leg in 3 All the corrective procedures afforded the desired results

In a 13 year old woman with a low open fracture of the femoral shaft and rupture of the quadriceps tendon quadriceps lysis ought to have been done during the post fracture period However the last part of the after treatment had been given in another hospital where this

procedure was omitted Later this patient was awarded a disablement pension

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also speaks for a restriction of the indications Out of our 37 Kuntsch nailed fractures 22 fulfilled the criteria set up by Key and Palmer respect to type and level of fracture Of the remaining 15 6 were fl oblique fractures and 9 slightly comminuted fractures in the midd third of the shaft The four cases of instability at the fracture site aft Kuntscher nailing belonged to this latter group Nail impacting r ported in the literature at a rate ranging from 3 per cent (Palmer 195 to 6 per cent (Dencker 1965b Tophoj & Sorensen 1968) did not occ in our material

Plate fixation was used for all cases of fractures not suited for medu lary nailing The procedure was employed in cases of multiple fra tures and complicated fractures of the shaft In special cases it wa also used to attain early mobilization or as a link in the fixation c fractures which proved difficult to reduce

Skeletal traction was the preferred treatment in cases where th type of fracture was not felt to be suited for medullary nailing and i which the above indications for plating were not present In patient where another injury had therapeutic priority plate fixation thoug indicated in accordance with the above was omitted if an institute conservative treatment was believed to be able to afford a good result

The low incidence of infections—one case—is remarkable in view of the relatively large number of open fractures and the use of open medullary nailing Such a low rate has been reported only by Madsen while others have had considerably higher rates (Bohler 1951 Palmer 1957 Dencker 1965a Wickstrom & Corban 1967 Tophoj & Sorensen 1968 Horsnaes 1968) Sepsis has been reported as a complication to Kuntscher nailing (MacAusland & Eaton 1963 Tophoj & Sorensen 1968)

On the basis of the present material consolidation of the femoral fracture seems to have occurred earlier than reported by others (Ni chols 1963 Smith 1964 Dencker 1965a Rokkanen et al 1969) How ever regard must be paid to differences in the therapeutic principles and in the criteria of healing Better conformity between the results is apparent from reports in which the time of return to work is stated (Nichols 1963 Rokkanen et al 1969)

Charnley & Gundy (1961) as well as Smith advise delayed osteo synthesis in candidates for Kuntscher nailing in order to avoid disturb ances of union In the present material the Kuntscher osteosynthesis was done as an immediate procedure in the great majority of cases without the result being characterized by delayed union or non union

Rokkanen et al (1969) also found no difference in healing time after immediate and delayed medullary nailing

The late results classified according to Dencker (1965a) are given in Table 9 Unlike Dencker we found no difference in the therapeutic results between closed and open fractures The good results compared with other materials classified according to Dencker (Dencker 1965a Tophoj & Sorensen 1968) must be viewed *inter alia* on the background of the corrective procedures carried out during the follow up period

The frequency of osteoarthritic changes in the adjacent joints interpretable with predominant likelihood as late sequelae of the trauma which caused the fracture is not known In the present material the frequency of secondary osteoarthritis in patients under 40 years of age may possibly prove to be too low if the follow up period is extended In two patients deformity at the fracture site is a possible aetiological explanation Incidentally this subject has not been elucidated in the literature

On the basis of the present material it seems justified to conclude that the problem concerning fractures of the femoral shaft relates mainly to the choice of the correct form of treatment paying regard to the character of the fracture concerned—presupposing that the technique and available armamentarium are optimal

SUMMARY

A retrospective analysis of the results of treatment in fractures of the femoral shaft during a 10 year period is reported The material is a traumatic one comprising 79 patients with 82 fractures 22 of which were open One-third of the fractures were but one component in multiple fractures Medullary nailing was done in 40 fractures 37 with the Kuntscher nail and three by the method of Rush Plate fixation was used in 11 fractures and 28 were treated by traction Two required only non weight bearing One patient died of another cause on the first day The early therapeutic results are reviewed

At follow up the late results could be assessed in 64 patients with 66 fractures The follow up period averaged 5 years The result is stated on the background of subjective complaints and objective *findings* according to the classification of Dencker A good result was obtained in all cases of medullary nailing Out of 10 fractures treated by plate fixation 9 obtained a good and one a poor result Out of 20 cases treated by traction 19 showed a good and one a satisfactory result

also speaks for a restriction of the indications. Out of our 37 Küntscher-nailed fractures, 22 fulfilled the criteria set up by Key and Palmer in respect to type and level of fracture. Of the remaining 15, 6 were flat oblique fractures and 9 slightly comminuted fractures in the middle third of the shaft. The four cases of instability at the fracture site after Küntscher nailing belonged to this latter group. Nail impacting, reported in the literature at a rate ranging from 3 per cent (Palmer 1957) to 6 per cent (Dencker 1965b, Tophøj & Sørensen 1968), did not occur in our material.

Plate fixation was used for all cases of fractures not suited for medullary nailing. The procedure was employed in cases of multiple fractures and complicated fractures of the shaft. In special cases it was also used to attain early mobilization or as a link in the fixation of fractures which proved difficult to reduce.

Skeletal traction was the preferred treatment in cases where the type of fracture was not felt to be suited for medullary nailing and in which the above indications for plating were not present. In patients where another injury had therapeutic priority, plate fixation, though indicated in accordance with the above, was omitted if an instituted conservative treatment was believed to be able to afford a good result.

The low incidence of infections—one case—is remarkable in view of the relatively large number of open fractures and the use of open medullary nailing. Such a low rate has been reported only by Madsen, while others have had considerably higher rates (Böhler 1951, Palmer 1957, Dencker 1965a, Wickstrom & Corban 1967, Tophøj & Sørensen 1968, Horsnæs 1968). Sepsis has been reported as a complication to Küntscher nailing (MacAusland & Eaton 1963, Tophøj & Sørensen 1968).

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The remaining group of 15 patients with 16 fractures is reported in a separate section The late results could not be assessed, as a follow up examination could not be performed Eleven out of the 16 fractures united without deformity 2 in slight varus deformity and 1 developed pseudarthrosis Seven out of the 15 patients died 5 of old age and 2 in connection with the fracture eliciting trauma and the surviving 8 had no relevant complaints on inquiry

Corrective procedures and delayed osteoarthritis of the hip and knee are discussed The socio economic status could be evaluated in 33 working patients

A conclusion is advanced on the basis of the above findings

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In view of this it may be presumed that anti inflammatory drugs such as salicylates indomethacin phenylbutazone and corticosteroid influence the acidity in inflamed tissues

This part of the study was designed to follow the pH behaviour for 15–30 minutes after corticosteroids were injected into rheumatoid joints and also 20–24 hours after the injection

MATERIAL AND METHODS

Twenty two patients were selected, all of whom fulfilled the requirements for the diagnosis of rheumatoid arthritis according to the American Rheumatology Association (Ropes 1959) The knee joint was chosen and in all there was a swelling and articular exudate The puncture with the measuring instrument was made from the lateral aspect after 1–2 ml of local anaesthesia with 1 per cent Carbocaine® with adrenaline had been administered intra and subcutaneously Care was taken not to inject the joint capsule as this might interfere with the synovial fluid conditions.

The steroids injected were in all patients methylprednisolonacetate 40 mg (Depomedrone®)

The pH measurements were made by a needle electrode as described in Part I of this study (Goldie & Nachemson 1969)

The joint cavity was reached by a larger needle (diameter 2 1 mm) with a pointed mandrin which was then extracted and the electrode inserted Care was always taken to place the electrode in the free joint cavity Reading was made after 2 minutes stabilization time In some cases the electrode was moved also to other parts of the joint without noticeable change in pH except that when joint cartilage was encountered an instantaneous drop in pH was noted.

After the readings had become constant the steroid was injected from the medial aspect of the knee as far as possible away from the pH electrode Registrations were made immediately on injection and 5 10 15 20 25 and 30 min after A tendency to stabilization was noted after 20–30 min A final registration 20–24 hours following the steroid injection was made in nine patients.

The pH of the hydrocortisone preparations was also measured using the same equipment

Four of the patients (Nos 19 20 21 22) received systemic steroid treatment at the time of measurements Two (Nos. 15 16) had previously been synovectomized. Three patients (Nos. 17 18 19) had received an intra articular injection of steroids 4–6 weeks prior to this investigation

RESULTS

The injected steroid solution itself had a pH around 5 0

As seen from Table 1 most of the rheumatoid knee joints showed an elevated hydrogen ion concentration prior to injection The mean pH in the non treated joints (Cases 1–14) was 6 7 ± 0 3 which agrees

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SYNOVIAL pH IN RHEUMATOID KNEE JOINTS

II. The Effect of Local Corticosteroid Treatment

IAN GOLDIE & ALF NACHEMSON

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Chronic inflammation gives rise to a local acidosis (Menkin & Warner 1937): the hydrogen ion concentration increases and the pH ranges around 6.5. The same condition exists in rheumatoid synovium, though statements of the pH value differ. *Ropes & Bauer* (1953) found an average pH of 7.22 as compared to 7.39 in normals and Cummings & Nordby (1966) reported variations from 7.08 to 7.28 with a mean of 7.22 in comparison to 7.43 as a normal value. The above mentioned values were all measured in synovial fluid withdrawn from the joints.

We have previously described intra-articular pH measurements in knee joints where we found in normal individuals a value of 7.3 and in rheumatoid arthritis 6.6 (Goldie & Nachemson 1969). The study was extended to measurements of synovectomized rheumatoid joints in order to establish whether removal of inflamed synovial tissue might alter the intra-articular pH. The results showed a mean of 6.8. Although the patients were symptom-free in the measured joints, the persistent acidity was believed to be due to a remaining inflammatory state in the regenerating synovial tissues, though of a lesser degree. It was thought that some inflammatory components might be lodged in the new synovium as a local target organ for the general chronic disease.

As yet there is no complete explanation of the acidity of inflamed tissues. It has been suggested that protein split products such as amino acids (Ropes & Bauer 1953) or increased glycolysis (Menkin 1956, Binzus & Tillman 1968) or release of hydrolytic lysosomal enzymes with subsequent connective tissue destruction (Dingle 1962, de Duve 1963) or depolymerization of hyaluronic acid (Asboe-Hansen 1966) or anoxia (Gardell 1966) may contribute to maintain tissue damage and thus local acidity. A combination of various factors may cause the increased hydrogen ion concentration in inflammation.

In view of this it may be presumed that anti inflammatory drugs such as salicylates indomethacin phenylbutazone and corticosteroid influence the acidity in inflamed tissues

This part of the study was designed to follow the pH behaviour for 15–30 minutes after corticosteroids were injected into rheumatoid joints and also 20–24 hours after the injection

MATERIAL AND METHODS

Twenty two patients were selected all of whom fulfilled the requirements for the diagnosis of rheumatoid arthritis according to the American Rheumatology Association (Ropes 1959) The knee joint was chosen and in all there was a swelling and articular exudate The puncture with the measuring instrument was made from the lateral aspect after 1–2 ml of local anaesthesia with 1 per cent Carbocaine® with adrenaline had been administered intra and subcutaneously Care was taken not to inject the joint capsule as this might interfere with the synovial fluid conditions

The steroids injected were in all patients methylprednisolonacetate 40 mg (Depo medrone®)

The pH measurements were made by a needle electrode as described in Part 1 of this study (Goldie & Nachemson 1969)

The joint cavity was reached by a larger needle (diameter 2 1 mm) with a pointed mandrin which was then extracted and the electrode inserted Care was always taken to place the electrode in the free joint cavity Reading was made after 2 minutes stabilization time In some cases the electrode was moved also to other parts of the joint without noticeable change in pH except that when joint cartilage was encountered an instantaneous drop in pH was noted

After the readings had become constant the steroid was injected from the medial aspect of the knee as far as possible away from the pH electrode Registrations were made immediately on injection and 5 10 15 20 25 and 30 min after A tendency to stabilization was noted after 20–30 min A final registration 20–24 hours following the steroid injection was made in nine patients

The pH of the hydrocortisone preparations was also measured using the same equipment

Four of the patients (Nos. 19 20 21 22) received systemic steroid treatment at the time of measurements Two (Nos. 15 16) had previously been synovectomized Three patients (Nos. 17 18 19) had received an intra articular injection of steroids 4–6 weeks prior to this investigation

RESULTS

The injected steroid solution itself had a pH around 5 0

As seen from Table 1 most of the rheumatoid knee joints showed an elevated hydrogen ion concentration prior to injection The mean pH in the non treated joints (Cases 1–14) was 6 7 ± 0 3 which agrees

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Department of Orthopaedic Surgery (Head: Professor Carl Hirsch, M.D.),
University of Gothenburg, Sweden

SYNOVIAL pH IN RHEUMATOID KNEE JOINTS

II. *The Effect of Local Corticosteroid Treatment*

IAN GOLDIE & ALF NACHEMSON

Received 6.x.69

Chronic inflammation gives rise to a local acidosis (Menkin & Warner 1937), the hydrogen ion concentration increases and the pH ranges around 6.5. The same condition exists in rheumatoid synovium though statements of the pH value differ. Ropes & Bauer (1953) found an average pH of 7.22 as compared to 7.39 in normals and Cummings & Nordby (1966) reported variations from 7.08 to 7.28 with a mean of 7.22 in comparison to 7.43 as a normal value. The above mentioned values were all measured in synovial fluid withdrawn from the joints.

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Table 2 Intra articular pH in earlier steroid treated patients following local injection of hydrocortisone

Patient no	17	18	19	20§	21§	22§	Mean
Before inject.	7 7	6 7	7 5	7 2	7 1	7 1	7 2
Immed. follow steroid inj	7.3	6 6	7 1	7 0	6 5	6 6	6 9
5 min after	6 8	6 9	7 6	7 5	7 4	6 7	7 2
10 min after	6 8	6 9	7 6	7 9	7 7	6 9	7 3
15 min after	7.8	7 1	7	7 9	7 7	6 9	7 5
20 min after	7 8	7 4	7 5	7 9	7 7	7 0	7 5
25 min after	8 0	7 3	7 5				7 6
30 min after	8 0						—
20 24 hours after	8 0	7 0	7 4				7 5

These patients received intra articular injection of steroid in the measured joint 1 2 months prior to investigation

These patients received systemic steroid treatment.

with the previously published measurements (Goldie & Nachemson 1969) where the pH in the diseased knee was 6 6 ± 0 2

Cases 17–22 presented in Table 2 had clearly elevated pH (7 2 ± 0 3) as compared with the others which is assumed to be due to systemic or intra articular steroid treatment previously administered

Immediately following the injection there was a sharp drop in pH (average 0 4 ± 0 2 pH units) probably due to the steroid solution itself This decrease in pH remained for some minutes but then there was a slow increase in all subjects which became noticeable in all instances after 10 minutes (see Tables 1 and 2) Thereafter a slight increase was observed up to 30 minutes In nine patients recordings after 20–24 hours showed the pH still maintaining an increased value equal to the measurements 30 minutes following injection with one exception (Case 10) where there was no change in pH after 30 minutes but 0 4 pH units after 22 hours

In all but three patients the pH after 15 minutes had surpassed the original value In Cases 10 and 19 the pH was the same as before injection and in Case 22 0 1 unit less The increase was on an average 0 3 pH units (Figure 1) The average intra articular pH in all the subjects measured at the particular intervals is seen in Figure 2

A statistical analysis between Cases 1–14 and Cases 17–22 showed that at most times there was a significant difference in pH with

Table 1 Intra articular pH in earlier untreated patients following local injection of hydrocortison

Patients nos	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
Before inj	6 9	6 6	6 4	6 6	7 0	7 0	6 6	6 9	6 0	6 9	6 4	7 1	6 5	6 6	6 9	6 9	6 7
Immed follow steroid inj	6 3	6 2	6 0	6 3	6 5	6 6	6 3	6 3	5 7	6 6	6 5	6 7	6 1	6 3	6 4	6 7	6 3
5 min after	7 0	6 6	6 6	6 7	7 0	7 3	6 3	7 0	6 1	6 9	7 0	6 9	6 5	6 6	6 9	7 1	6 8
10 min after	7 1	6 7	6 7	6 8	7 1	7 5	6 7	7 4	6 3	6 8	7 2	7 2	6 8	7 3	7 0	7 1	7 0
15 min after	7 1	6 7	6 8	6 9	7 2	7 5	6 9	7 3	6 8	6 9	7 2	7 3	7 0	6 9	7 0	7 1	7 0
20 min after	7 2			6 9			7 0	7 0	7 1	6 9	7 3	7 4	7 1	7 3		7 2	7 1
25 min after									7 1	6 9	7 2	7 5	7 2	7 3			7 2
30 min after									7 1	6 9	7 2	7 5	7 2	7 3			7 2
20–24 hours after									7 1	7 3	7 3	7 6	7 4	7 4			7 3

These patients previously synovectomized in the measured knee joint

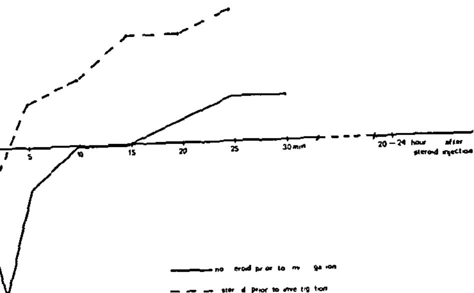


Figure 2 Average intra articular pH before and after intra articular injection of corticosteroid in earlier untreated and in earlier steroid treated patients with rheumatoid arthritis

synovectomized patients were excluded The pH measured in these joints was the same as presented in Part I of this study (Goldie & Nachemson 1969)

The increase in pH noted from 15 minutes and thereafter following the *injection* of steroid is statistically highly significant ($p < 0.01$)

No complications following the measuring procedure were observed

COMMENT

It is evident from this investigation that intra articular deposited corticosteroid preparations though very acid themselves cause an alteration towards the normal side of the pH scale in rheumatoid arthritis In Part I of this study the pH of normal knee joints was 7.3 ± 0.2 (Goldie & Nachemson 1969) The initial sharp drop as registered on the introduction of the steroid obviously seems to be a direct action of the injected fluid The ensuing increase may be explained by the various

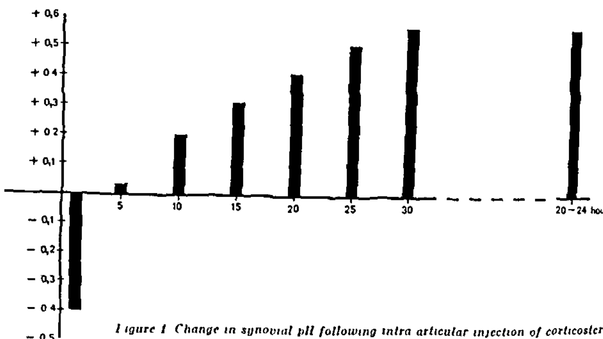


Figure 1 Change in synovial pH following intra articular injection of corticoster in 22 patients with rheumatoid arthritis

higher values in Cases 17–22 who had received earlier steroid treatment (Table 3)

On the other hand the statistical analysis did not demonstrate any major difference between the two groups with regard to the increase in pH following the injection (Table 4) In these comparisons the two

Table 3 Mean values and t statistics of the intra articular pH following hydrocortisone injection in earlier untreated (Cases 1–14) and earlier steroid treated (Cases 17–22) patients

	Cases 1–14 Mean ± SD	Cases 17–22 Mean ± SD	t value
Before inject	6.7 ± 0.3	7.2 ± 0.3	3.48
Immed follow steroid inj	6.3 ± 0.3	6.9 ± 0.3	3.89
5 min after	6.8 ± 0.3	7.2 ± 0.4	2.38
10 min after	7.0 ± 0.3	7.3 ± 0.5	1.[illegible]6
15 min after	7.0 ± 0.2	7.5 ± 0.4	3.17
20 min after	7.1 ± 0.2	7.5 ± 0.3	not perf
25 min after	7.2 ± 0.2	7.6 ± 0.4	not perf
30 min after	7.2 ± 0.2	—	not perf
20–24 hours after	7.3 ± 0.2	7.5 ± 0.5	not perf

The relationship between increased hydrogen ion concentration in tissues and pain has been investigated by Revici et al (1949) and Lindahl (1961) among others Revici et al believe that local changes in damaged tissues may bring about a lowering of the nerve threshold for pain and that end organs ordinarily concerned with other forms of sensation are altered in such a way that the impulses originated by them evoke the sensation of pain Lindahl has offered evidence of the relationship between increased hydrogen ion concentration and severe pain in the skin whereby the hydrogen ion may be the chemical mediator which triggers the pain stimulae in the nerve endings

A variety of pain mechanisms could be at play in rheumatoid arthritis for example capsule and ligamentous engagement and bone involvement The low synovial fluid pH may be part of the mechanisms which elicit joint pain It is generally accepted that local steroid treatment relieves pain in rheumatoid joints The reason for this may be the demonstrated tendency to normalize the pH

SUMMARY

Previous studies have shown that the pH in rheumatoid joints is decreased below the normal of blood and organ tissues and also below that of normal joints

By using a direct intra articular method we have been able to confirm our results in an earlier investigation that the hydrogen ion concentration in rheumatoid joints averages a pH of 6 7 The problem in this study has been to investigate whether local application of corticosteroids influences the synovial pH In 22 patients it was found that within 20 minutes after steroid injection a statistically significant increase of pH followed to a level well above the initial values in all except one joint On an average the increase was 0 3 pH units In nine patients measurements were made 20-24 hours after the injection and the pH still remained increased

Although from the start a significant difference existed in pH between those knees that were previously not treated (6 7 ± 0 3) and those earlier treated with steroid (7 2 ± 0 3) the response to the injected steroid with regard to pH increase was not significantly different

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Table 4 Change in pH following injection of steroid in rheumatoid knee joints

	Cases 1–14 Mean ± SD	Cases 17–22 Mean ± SD	t value
Immed follow steroid inj	−0.4 ± 0.2	−0.4 ± 0.2	<1
5 min after	+0.1 ± 0.2	−0.1 ± 0.5	<1
10 min after	+0.3 ± 0.2	+0.1 ± 0.6	1.14
15 min after	+0.3 ± 0.2	+0.3 ± 0.4	<1
20 min after	+0.5 ± 0.3	+0.3 ± 0.4	<1
25 min after	+0.6 ± 0.4	+0.3 ± 0.3	not perf
20–24 hours after	+0.7 ± 0.2	+0.2 ± 0.2	not perf

buffering mechanisms which regulate the hydrogen ion concentration in both blood and extravascular tissues (Salenius 1957, Saunders et al 1960). The buffering requires a normal fluid equilibrium and cannot exert its full influence in damaged tissues. It appears that the steroid has to be given some time *10–20* minutes to interact with the tissue dynamics before buffering takes place. The turnover of intra-articular deposited steroids is rapid, ranging from 5 to 120 minutes (Wilson et al 1953, Peterson et al 1959, Winter et al 1967, Murphy & West 1968). *After this time the buffering mechanisms may come into force.* This investigation indicates such a possibility. Our findings are also in agreement with those of Binzus & Tillman (1968) who noted a drop in pCO_2 and increase in pO_2 on prednisolon injection in rheumatoid knees.

In rheumatoid synovial inflammation small organelles are encountered within granulated cells, preferably neutrophils but also macrophages. These organelles, lysosomes, normally play no part in intracellular metabolism. By phagocytosis of foreign materials and by an own the lysosomes disrupt and release their proteo- and hydrolytic enzymes (de Duve 1963, Weissmann 1965, Gardell 1966). They contribute to maintaining inflammation and acidity. Part of the steroid action —like that of salicylic acid, phenylbutazone and indomethacin—is stabilization of the lysosomal membranes (Weissmann & Thomas 1964, *Holt et al 1968*).

Hyaluronic acid is of importance to the capillary wall function. Depolymerization increases the permeability of the vessel wall. Corticosteroids polymerize hyaluronic acid (Nettelbladt & Sundblad 1963) and the abnormal permeability of the capillary wall is ceased. This occurs via an antihyaluronidase action by the corticosteroids (Brunius 1968).

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SHORTENING IN PSEUDARTHROSIS TREATMENT WITH THE KÜNTSCHER DISTRACTOR

NIELS OLAF CHRISTENSEN

Received 11 vi 69

Shortening in pseudarthrosis may be due to loss of substance by resorption displacement of fragments or more often a combination of both

The problem deserves consideration in the planning of treatment and the aim should be to leave the patient with as little shortening as possible In many cases it is impossible to correct the shortening at the time of operation and it would seem necessary to make a resection in order to accomplish reduction of the fragments However this means of treatment neglects the shortening and should not be recommended at any rate not as far as the lower extremity is concerned

Preoperative traction of conventional type is insufficient The weight which is needed could not practically be applied even by lowering the upper end of the bed

Pseudarthroses may of course be very mobile but then shortening is often considerable and the last part of the elongation process takes as much force as in firm pseudarthroses

The ideal would be elimination of the shortening preoperatively so that apposition of the bone ends is the only reduction needed at operation

A reasonable period of time must be allowed for the soft tissue structures to adapt themselves to the changes of tension that follow We have been using the Küntscher distractor in the preoperative treatment of some cases of pseudarthrosis with shortening The principle will be understood from Figure 1 Kirschner wires proximal and distal to the pseudarthrosis are the puncta fixa which are connected by the apparatus and traction is accomplished by screwing the Kirschner wires apart In the case of a femur the wires are put through the spina iliaca ant sup and the distal femur In the tibia they are put through the proximal and the distal part of the bone (The calcaneus has been

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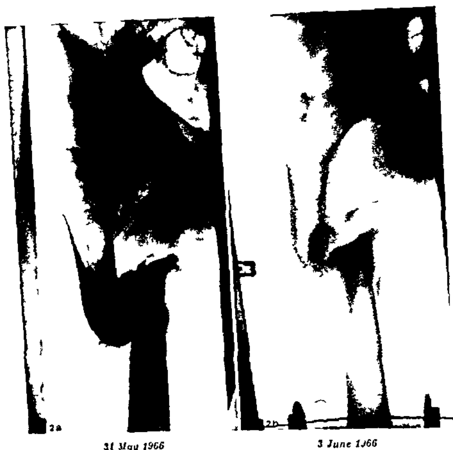
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31 May 1966 3 June 1966

Figure 2

often been underestimated The reaming which always precedes nail ing might be of importance in promoting healing

Two case histories illustrate the effect of the treatment

Cas 1 (See Figure 2) 35 year old man with a very mobile pseudarthrosis of his ght femur after a fracture when he was 0 The fracture was treated primarily by Lane plate and cerclage Infection followed and a fi tula was discharging for many m nths. The metal was removed. The fracture did not heal and an increasing sh rtening followed finally a total of about 10 cm. The right knee was practically tiff In 196 there was a flare-up of the infection The patient was seen by us in 1966 The infection was then quiet.

After 6 w eks of di tractor treatment a Kuntscher nailing was performed. A new flare up of the infection followed In sp te of prophylactic treatment with cloxa

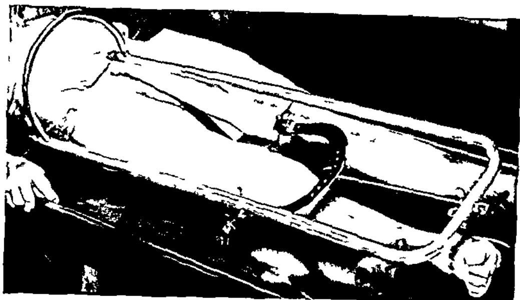


Figure 1 Distractor applied for traction on the femur

suggested but it seems unnecessary to submit the ligamentous structures of the ankle joint to this very strong traction) At the same time a fibulotomy must be done The fibula has generally healed

The screwing of the distractor is done at a rate of 1–2 mm a day Moderate pain is often experienced by the patient but disappears after a while

By this procedure it is possible to break up even very firm pseudarthroses We have seen no unfavourable reactions from the muscles the vessels or the nerves A mild infection at the spina has been observed but it subsided quickly after removal of the distractor The spina is actually rather fragile as an anchoring point We have seen cutting through by the Kirschner wire here after weeks of traction but it has been possible to apply the distractor again if necessary and to continue the treatment A special metal cylinder threaded over the Kirschner wire has been recommended to prevent this complication

After distractor treatment rigid fixation is extremely important The mechanical demands on osteosynthetic material and its fixation to the bone are great It is an advantage therefore if the pseudarthrosis allows fixation with a heavy Kuntscher nail This method generally gives a reliable stability and makes early mobilization possible Additional measures such as bone grafting will only be necessary in exceptional cases and resection of bad pseudarthrosis tissue should not be done The sclerotic masses have a potential healing capacity which has



17 April 1968 — 6 May 1968

Figure 3

SUMMARY

The effect of the Kuntscher distractor is illustrated by two cases with shortening of the femur and the tibia because of pseudarthrosis



15 July 1966



2a

4 April 1968

Figure 2

cillin. Drainage brought the infection under control, but a fistula persisted. Weight bearing was allowed after a few days. The pseudarthrosis healed. Only after extraction of the nail could the infection be treated effectively and has not recurred (1¼ years). 5 cm shortening remained because of defect.

Case 2 (See Figure 3). 22 year old man, who had a fracture of the right tibia and fibula in a traffic accident 1965. He was treated conservatively with traction and plaster. The fibula healed, the tibia did not. He had been walking all the same and an increasing shortening and varus deformity followed. In April 1968, after a fibulotomy, the distractor was applied. After one month of traction Küntscher nailing was performed. Weight bearing was allowed early. The pseudarthrosis healed.

The distractor is delivered by Firma Waldemar Link, Steilshooper strasse 155, Hamburg 33.

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17 May 1968

13 January 1969

Figure 3

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(Cont co er pag 3)

Acta orthop Scandinav 41 1 9 133 1970

Department of Surgery Vaasa Central Hospital Finland

MAST CELLS IN ENDOSTEAL AND PERIOSTEAL BONE REPAIR

A Quantitative Study on Callus Tissue of Healing Fractures in Rabbits

RALF V LINDHOLM & T SAM LINDHOLM

Received xi 1968

After the precise description of the histological picture of a healing fracture by Pritchard & Ruzicka (1950) Pritchard (1964) 14 years after that contribution concluded that the basic problems of fracture healing are histogenetic and will remain obscure until the mechanisms of normal developmental processes have been revealed

The fact that mast cells aggregate in the mesenchymal part of the periosteal callus of healing fractures in rats has recently been recognized (Lindholm Lindholm & Liukko 1967)

The following experiments have been performed in order to (A) reveal mast cells in the internal (endosteal) callus and (B) compare the mast cells counts of the endosteal and the periosteal callus or of the two different kinds of osteo regeneration called intramembraneous and endochondral osteogenesis

MATERIAL AND METHODS

The material consisted of 17 rabbits of both sexes, weighing on an average 1568 g. The animals had been reared under the usual laboratory conditions

In pentothal intra enous anaesthesia the right antebrachium was manually fractured. The leg was left unsplinted and the animals could move around without much disability The animals we e sacrificed and histological specimens were taken on lay 2 3 4 5 6 7 8 9 10 11 14 16 17 after fracturing. Each time two sample were taken one from the external (periosteal) callus and another from that part of the internal (endosteal) callus situated just at the end of the open m rrow cavity a oiding any inclusion of bone marrow proper The preparations were fixed in a 4 per cent aqueous solution of basic lead acetate and stained in a 1 per cent toluidine blue aqueous solution as earlier described (Lindholm Lindholm & Liukko 1967) No decalcification was performed. The mast cells were counted

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Figure 1. X rays of a 17 day old experimental fracture in a rabbit

in the fibrous part of the callus in perpendicular lines against the newly formed cartilage according to a technique described previously (Lindholm, Lindholm & Liukko 1967).

RESULTS

In the endosteal callus cartilage and new bone appear about the fourth to fifth day of fracture repair. In the periosteal callus this occurs on an average between the sixth and eighth day. On the seventeenth day the fracture appears both clinically and roentgenologically consolidated (Figure 1). Mast cells could be demonstrated in the fibrous parts of the endosteal callus (Figure 2) as well as in the periosteal callus.

Curves representing endosteal and periosteal callus (Figure 3) show the mean relationship between the mast cell counts obtained. According to the curves mast cells in the periosteal callus are twice as numerous as in the endosteal on the fifth to seventh days of callus formation. It has not been possible statistically to state the degree of significance of this trend.

DISCUSSION

The local factor in bone growth responsible for the calcification of the collagen fibril is probably a mucopolysaccharide substance closely related to chondroitin sulphate (Sobel 1955). In the calcifying region of bone there are substances present which can take up S^{35}. The fact has recently been discovered that mast cells are preferential spots of S^{35} up take in the periosteal callus of healing fractures in rats (Lindholm & Lindholm 1968). The mast cell, unmatched in its remarkably high content of biologically active constituents, is able to carry Ca ions to calcifying

Figure 2 Photomicrograph of mast cells in the endosteal callus of a 5 day old experimental fracture in a rabbit (× 1000 toluidine blue 1 per cent)



NUMBER OF MAST CELLS / mm^3

3000
2000
1000
0

0 5 10 15

DAYS

Figure 3. Mast cell counts in the periosteal (external) callus (----) and in the endosteal (internal) callus (——) of experimental fractures in rabbits

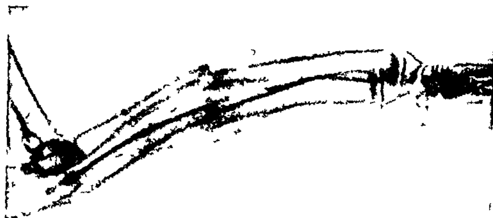


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It is possible that the higher mast cell counts in the periosteal callus correlate to the different biomechanical situation in the outer parts of the callus cuff as compared with the inner callus Movements between the fragments are reflected to the callus mass in direct proportion to the distance between the axis of the long bone and the point of callus under observation It is known that rigid immobilization of a fracture tends to minimize the formation of cartilage (Lettin 1967) while movements in excess are apt to cause cartilage in abundance (Lindholm Lindholm Leino & Loikkanen 1968) The mast cell reaction may only be a compensatory response to unfavourable conditions of healing It is very questionable to what extent the different types of osteogenesis the intramembraneous and the endochondral in fact represent principally different mechanisms biologically Cartilage formation in excess apparently only represents an unfavourable aberration of the same process More or less cartilage apparently depends on more or less movement

SUMMARY

A quantitative study on mast cells in the callus tissue of experimental fractures in rabbits has been performed Mast cells aggregate in both the endosteal (internal) and the periosteal (external) parts of the callus cuff Simultaneous counts showed considerably higher counts on the fifth to seventh days in the periosteal callus in comparison with those obtained in the endosteal callus The speculation is presented that this phenomenon may be due to biomechanical factors and may correlate to the excess of cartilage formation in the case of movements in the fracture site

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SUMMARY

A quantitative study on mast cells in the callus tissue of experimental fractures in rabbits has been performed. Mast cells aggregate in both the endosteal (internal) and the periosteal (external) parts of the callus cuff. Simultaneous counts showed considerably higher counts on the fifth to seventh days in the periosteal callus in comparison with those obtained in the endosteal callus. The speculation is presented that this phenomenon may be due to biomechanical factors and may correlate to the excess of cartilage formation in the case of movements in the fracture site.

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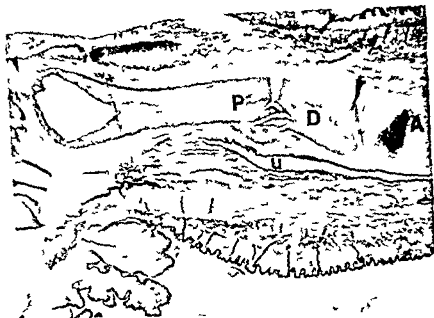


Figure 1 Four weeks aft r a manual fracture two thirds along a mature shaft un on has been achieved by a ventral callus The base of the bone s proximal en largement has a dorsal spur of fibrocarl lage (arrow) Endochondral growth at the base has ceased The distal bone piece is attached to part of the fibrous cap or ante ior process × 17

Abbreviat ons A = the anterior process D = the distal bone piece after fracture P = the proximal bone p ece after fracture u = the urethra

MATERIALS AND METHODS

One hundred and four hooded Norwegian rats were used The form and development of the rat s penile bone and its anterior process have been described by Ruth (1934) and Wiesner (1934) The bone in its full extent is shown in Figure 1 In nine the attempts at fracture broke only the anterior process or else failed to interrupt the shaft Nineteen successful fractures were made but became infected or the distal bone fragment was lost Seventy six rats were theref re available for study they wer grouped as follows

Gr ups Ia and b G oup Ia omprised twenty five young animals (between five and seven w eks of a e) weighing between 96 and 182 g Group Ib c nsisted of tw nt nine matu e rats eighing between 340 and 665 g. Under ether *anaesthesia* the penis was protru led through the prepuce clamped a ross its base and swabbed clean with 0 per cent ethyl alcohol The shaft of the os priapi was cut through with p inted scissors via a dorsolateral approa h The soft tissue wound was closed w th tw or three interrupted sutures in the *mature rats* but left open in the

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HEALING IN THE EXPERIMENTALLY FRACTURED OS PRIAPI OF THE RAT

WILLIAM A BERESFORD

Received 23 ii 69

Among the naturally occurring extra skeletal bones found in various mammalian species, the os priapi occurs in many is easily accessible for fracturing and its elongated form lends itself for comparison with the long supporting bones of the skeleton proper A search of the literature revealed no previous study of healing in an os priapi

Healing of the shaft of the os priapi was considered in light of the observations and hypotheses developed from many studies of skeletal fractures and lesions Firstly the environment of dense connective tissue in which the bone lies might predispose to a fibrous union Secondly the bone develops partly in cartilage and partly by direct ossification McLean & Urist (1961) at one time suggested that only bones formed endochondrally develop cartilage in their callus of fracture an analysis of the callus constitution in fractures at various points along the length of the shaft might reveal whether their view is justified for this bone Thirdly the relative contribution of periosteum and endosteum to fracture callus is still debated The shaft of the os priapi is long in form but has no marrow cavity only narrow vascular channels Can a fracture of it therefore be viewed as comparable with a skeletal lesion elsewhere involving only cortical bone and how do its vascular channels react? Fourthly it would be of interest to compare the healing of the os priapi with that reported for the long bones skull and mandible of the rat and other species in regard to the nature and speed of the repair the width of gap which can be bridged and the influence of age on the course of healing With these considerations in mind fractures of the os priapi were made in two groups of rats—young and mature—and their healing was followed histologically

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Group 3 Ten unoperated rats of various ages served as controls indicating the state of development of the intact bone for comparison with the operated rats in Group 1a.

After a celibate survival of from four days to thirty weeks the animals were killed with chloroform. The distal penis was fixed in Heidenhain s Suza solution before decalcification in a solution containing 5 per cent formic acid and 10 per cent formalin The penis was imbedded in paraffin cut longitudinally at 7 μ and the sections stained with haematoxylin and eosin or with van Gieson s stain.

The width of the fracture gap at its narrowest point, dead bone to dead bone was measured during microscopy using a stage micrometer and the results are given in Tables 1 and 2 To arrive at the factor by which the tissues had shrunk during processing several penises were measured for length (ln) at the time of fixation and later as a section (ls) on the slide ls/ln was 0 8

RESULTS

General Features

The successful sixty six fractured bones regularly had some separation of the resulting distal and proximal pieces and as an indication

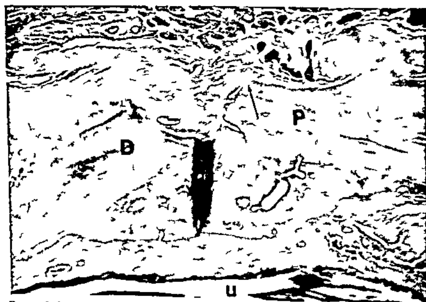


Figure 2 Sixteen weeks after severance of a mature bone the angulated bone pieces are united by a dense bony central callus Most of the gap is densely fibrous and the dorsal corner of the proximal margin (arrow) has been rounded off The dorsal callus lies some way back from that margin The distal piece s end face has a thin layer of new bone × 42

Table 1 Severed fractures of os priapi
Group Ia Mature

Survival period (weeks)	Fracture gap s width (mm) and kind of union 0 = non union Uc = union by cartilage Ub = union by bone 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0	>1 0
0–2	0 0 0	0									
2–5		Uc	0 0 Uc 0	0 Uc 0	Uc						0
5–10			Uc	Uc Uc				Uc Uc	0	Uc	
10–26		Ub		Uc Ub			0 Ub	0 Ub	0		

Total animals = 29 total Uc and Ub = 15

Group Ib Young

0–2	0	0 0	0	0						0	
2–5	Uc				0 Uc	Uc Uc	0	Uc			
5–10			0			0		0 Uc			
10–30		Ub Ub Ub		Ub Ub	Ub Ub		0				

Total animals = 25 total Uc and Ub = 13

Table 2 Manually broken os priapi

Survival period (weeks)	Fracture gap s width (mm) and kind of union <0 1				0 1	0 2
2–5	Uc	Uc	Uc		Uc	
5–10	Ub	Ub	Ub	Ub	Ub	Uc
10–12	Ub				Ub	

Total animals = 12 total Uc and Ub = 12

younger ones The clamp was removed and the penis pushed back un splinted into the prepuce

Group 2 In twelve mature rats weighing from 360–670 g closed fractures of the shaft were made manually

Group 3 Ten unoperated rats of various ages served as controls indicating the state of development of the intact bone for comparison with the operated rats in Group 1a

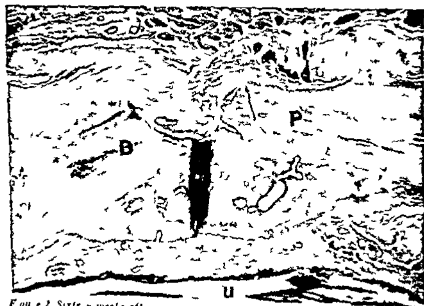
After a celibate survival of from four days to thirty weeks the animals were killed with chloroform. The distal penis was fixed in Heidenhain s Suza solution *before decalcification* in a solution containing 5 per cent formic acid and 10 per cent formalin The penis was imbedded in paraffin cut longitudinally at 7μ and the sections stained with haematoxylin and eosin or with van Gieson s stain

The width of the fracture gap at its narrowest point, dead bone to dead bone was measured during microscopy using a stage micrometer and the results are given in Tables 1 and 2 To arrive at the factor by which the tissues had shrunk during processing, several penises were measured for length (ln) at the time of fixation and later as a secti n (ls) on the slide ls/ln was 0 8

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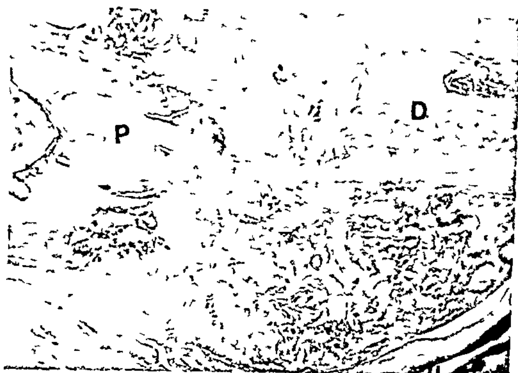


Figure 3 Three weeks after a manual fracture of a mature shaft cartilaginous union has been achieved by a strong ventral periosteal outgrowth of callus The distal piece is deficient dorsally in callus thus no true periosteal collar has developed for this piece Dense fibrous tissue separates the urethral epithelium from the ventral callus × 67

of the instability of their gap the pieces were angulated once to 80 of misalignment but usually to 10–40 (Figure 2) Bone fragments occasionally separated from the shaft ends but comminution was never a marked feature The instability was arrested in some animals by the achievement of bony or cartilaginous bridging of the gap The gap width (uncorrected for shrinkage) kind of union and approximate survival period for each animal with a severed os are presented in Table 1 and for those with a manually broken shaft in Table 2 Each animal is represented by letters Ub denotes a continuous link of new bone across the gap Uc that the osseous link was interrupted by cartilage and 0 that bridging by any kind of cartilage or bone had not taken place

Cartilaginous union sometimes took place as early as two weeks after severance but six animals survived for several weeks with gaps as narrow as 0 4 mm (corrected approximately by the factor for shrink

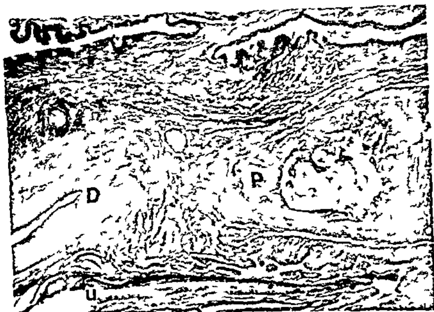


Figure 4 Three weeks after severance in a young rat the fracture gap is fibrous and the bone pieces angulated Active endochondral growth is present along the base of the proximal enlargement with its marrow cavity A vascular channel runs within the distal bone × 49

age) remaining fibrous The frequency of union in animals living post operatively for two weeks or more is not significantly ($\chi^2 = 0\ 35$) higher in the younger group of rats 13/19 compared with 15/25 for the mature rats

The separation was much less in the animals with manually broken shafts (Figure 1) (Table 2) union was seen in every animal and the first bony bridging was noted at five weeks instead of ten weeks required for a cut os

Events in the Fracture Gap and at the Bone Ends

The angulation of the shaft pieces resulted in a fracture gap which was narrow on the ventral urethral side but wider on the dorsal side of the os priapi The gap was bounded by the two bone margins and in dorsal and ventral areas by severed dense fibrous tissue with the urethra close by ventrally Young fibroblastic tissue grew into the gap

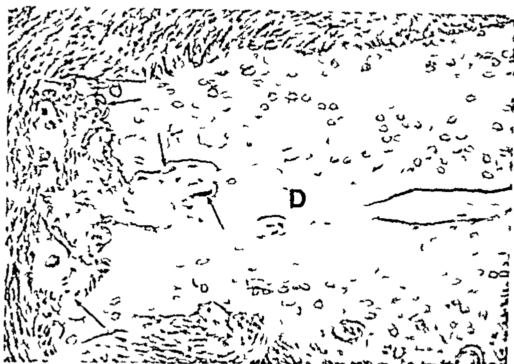


Figure 5 Three weeks after severance of a young bone distal end face and open vascular canal have several sites of osteoclastic erosion (arrow) There is a slight onlay of new bone just within the eroded canal Young fibroblastic tissue occupies the gap × 67

(Figures 3 and 5) and in the instances of persistent non union could become dense (Figure 4) and oriented transversely across the gap

The distribution of the callus growing from the shaft ends bore a consistent relation to the angulation (Figures 1 and 2) The dorsal sides of the shaft usually developed only a little callus and often this was situated some way back from the cut margin because the dorsal corner was undergoing erosion to a rounded smoother contour (Figure 2) The ventral shaft surfaces developed considerably more callus tissue Hyaline cartilage formed near the margin and new bone grew under the periosteum further back from the edge and advanced into the cartilage by endochondral ossification (Figure 3) Some of this callus cartilage extended to cover a little of the cut end face but most of the length of the cut margin was in contact with other kinds of tissue to be described later

In some animals the ventral calluses of hyaline cartilage and new bone grew out sufficiently in the first two or three weeks to meet and fuse thereby achieving an early cartilaginous union Seldom however



Figure 6 Five weeks after severance the dead bone ends are joined in the ventral one of their gap by transversely disposed fibrocartilage experiencing invasion by bone forming elements at several sites (arrow) × 167

did very high standing bony trabeculae arise Bony consolidation of the ventral callus save only very small areas of calcified cartilage was achieved by Group 1 rats between the 10th and 15th weeks and between the 7th and 9th by Group 2

In many animals fibrous connective tissue fibrocartilage and a form of cartilage with sparsely distributed cells and a pale non fibrous and apparently amorphous matrix were seen in the gap These three tissues exhibited areas of transition with one another and with the new hyaline cartilage and bone They also tended to have a particular distribution related to the angulated bone-ends Fibrous connective tissue usually occupied the wide dorsal aspect becoming transversely disposed in the narrower ventral region where it might merge with fibrocartilage If present this fibrocartilage also lay transversely and served to unite the osteo-cartilaginous ventral calluses with which it merged (Figure 6) The usual site for the acellular amorphous cartilage was close to and fused with part of the dead bone of the broken margin (Figure 7)

The end faces early in healing had dead bone undergoing some osteoclastic erosion or lying in contact with young connective tissue cells

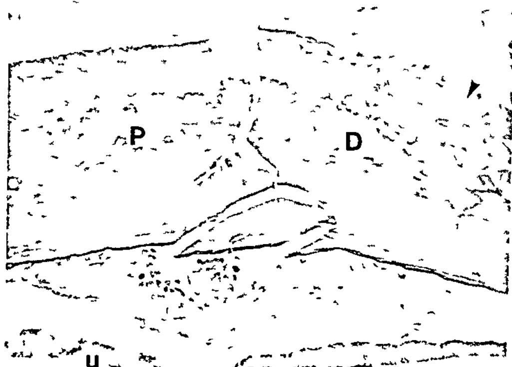


Figure 7 Four weeks after a manual fracture whose distal position along the shaft is shown in Figure 1 The ventral bridging callus has osteocytes many chondrocytes and near the dead bone some pale acellular matrix The end faces and dorsal shaft surfaces show no callus The firm attachment of the distal piece to the fibrocartilaginous anterior process is arrowed × 67

acellular matrix or hyaline cartilage near the ventral side of the shaft The vascular channels opened up in the lesion held osteoclasts (Figure 5) and young connective tissue Later a single layer of osteoblasts lined most of the widened channels and some of the end face and laid down a thin layer of new bone (Figure 2) This seemed to be more a matter of sealing off of the bone end from the dense connective tissue of the gap than a significant contribution of callus towards union

In conclusion then the calluses which developed were periosteal but with a ventral predominance rather than forming symmetrical collars around the bone ends

Special Features

In two animals with fibrous union some islands of urethral epithelium lay within the connective tissue situated between the bone ends Neither here nor in any of the other rats did any bone or cartilage

form especially close to the epithelium or separated from the calluses (Figure 2)

The young rats were operated upon at a time when endochondral growth was still active along the base of the proximal enlargement However when killed the presence (Figure 4) or absence (Figure 1) of active cartilaginous growth corresponded to that of the controls (Group 3) of similar ages at the time of death There was no evidence that fracturing the shaft had stimulated endochondral growth at the base or had deferred its cessation

In contrast to the older group the young rats developed slightly more callus on the sides of the shaft The volume of callus in the gap itself was not obviously greater and as has been mentioned did not lead to a significantly higher incidence of union

The bones broken manually differed in their behaviour from that described for the severed os only in the narrowness of the gap from which fibrocartilage was absent and the earlier bony replacement of the ventral cartilaginous callus (Figure 7)

Most breaks came in the middle region of the shaft but several involved the distal part including the tip underlying the distal fibrocartilage Cartilage cells were regularly observed in the callus tissues in these distal fractures (Figures 1 and 7)

Ossification of Anterior Process

An incidental finding was made in the dense distal or anterior process to which the tip of the os priapi attached (Figures 1 and 7) Ruth (1934) and Wiesner (1934) mentioned this structure as being fibrous or fibrocartilaginous They did not report the basophilia and endochondral ossification substituting in its dorsal region (Figure 8) that were seen here in all the mature rats and most of the control and young rats The bone formed in the anterior process is irregular in structure with many spaces No instance of fusion of this bone with the penile bone was noted There are therefore two bony structures in the penis of the mature rat to which the term os priapi might be applied

DISCUSSION

General characteristics Several general features emerged as characteristic for these fractures of the os priapi The angulation of the bone pieces with the bulk of the callus forming within the lesser angle the inconsistent achievement of union and a union in which transversely

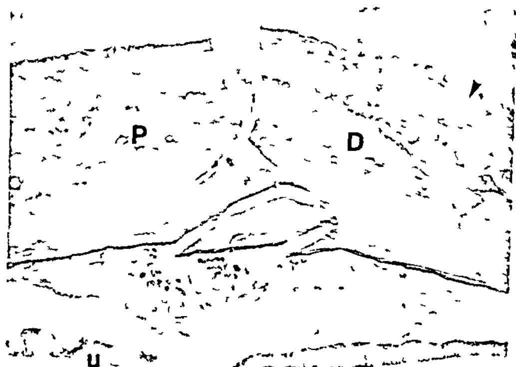


Figure 7 Four weeks after a manual fracture whose distal position along the shaft is shown in Figure 1 The ventral bridging callus has osteocytes many chondrocytes and near the dead bone some pale acellular matrix The end faces and dorsal shaft surfaces show no callus The firm attachment of the distal piece to the fibrocartilaginous anterior process is arrowed × 67

acellular matrix or hyaline cartilage near the ventral side of the shaft The vascular channels opened up in the lesion held osteoclasts (Figure 5) and young connective tissue Later a single layer of osteoblasts lined most of the widened channels and some of the end face and laid down a thin layer of new bone (Figure 2) This seemed to be more a matter of sealing off of the bone end from the dense connective tissue of the gap than a significant contribution of callus towards union

In conclusion then the calluses which developed were periosteal but with a ventral predominance rather than forming symmetrical collars around the bone ends

Special Features

In two animals with fibrous union some islands of urethral epithelium lay within the connective tissue situated between the bone ends Neither here nor in any of the other rats did any bone or cartilage

replaced An hypothesis of perhaps general application can be proposed any cartilage tissue bridging a fracture gap will eventually be replaced by bone in endochondral ossification In particular this is probable in the rat s penis since the distal fibrocartilage already described regularly undergoes some replacement ossification in the unoperated rat Fibrocartilage linking penile fractured bone-ends would be expected to be at least as prone to ossification as that structure

Assuming the eventual substitution of bone for cartilage a fracture may be deemed united when it is linked by a continuous band of tissues containing osteocytes or chondrocytes Union so defined histologically occurred in twenty eight of forty five animals with severed bones surviving for two weeks or longer This incidence of minimal union the narrowness of the gaps around ½ mm sometimes remaining ununited and the relatively long period for bony consolidation of the callus tissues mark the os priapi as a site of poor bony healing

The rat unaided can bridge with bone gaps of 1 mm in the fibula and 2 mm in the rib (Mulholland & Pritchard 1959) but only 0 1 mm in the skull vault (Pritchard 1946) The widest gaps united by bone or cartilage in the os priapi were approximately 1 mm across but gaps of half that size sometimes remained fibrous The penile bone therefore falls between the skull vault and the long bones of the skeleton in its powers of regeneration

Internal callus One possible contributor to this poor repair is the lack of an endosteal or internal callus derived from a marrow cavity Vascular channels opened up by the cut were eroded and then a thin overlay of new bone appeared in them and on the dead end face The shaft end faces thus behave like injured skeletal cortical bone (Pritchard 1964)

Several authors stress the major contribution made to bony healing by the internal callus when cortical drill holes penetrate to the marrow cavity of long bones (Fly 1927 Bourne 1942 Melcher & Irving 1962) Luecking (1948) went further by maintaining that the internal callus was more important than the external for the repair of complete tibial shaft fractures in rats What occasions the vigorous internal callus in fractures and penetrating holes in long bones and is deficient in the marrow less shaft of the os priapi may be *space* for abundant internal bone formation or numerous marrow *osteoprogenitor cells* or both these factors

Fibrous situation and age Another factor acting against bony union may be the dense fibrous situation in which the os lies which could



Figure 8 In the distal tip of the mature penis the fibrocartilaginous anterior process lies above the urethra and is partly replaced in its dorsal region by labyrinthine bone × [illegible]

disposed fibrocartilage often participates constitute a picture closer to that described by Pritchard (1964) and Aho (1966) for unstabilized fractures of the rat's tibial shaft than any other experimental fracture reported

Pritchard (1964) believed that forces from attempted use of the injured limb were important in causing fibrous connective tissue to be transformed to fibrocartilage in the narrow part of the tibial gap The forces acting on the broken os priapi are unlikely to approach in magnitude those experienced by bones bearing the animal's weight Nevertheless some mechanical factor is presumed to have caused the angulation regularly seen and where the gap between the calluses was very narrow that factor may have resulted in some transformation of fibroblastic tissue into fibrocartilage

Union Ignoring the controversial question of whether or not connective cartilaginous and osseous tissues can in the transition zones observed slowly transform one into another the process of tissue replacement undoubtedly plays a role in fracture repair Callus hyaline cartilage certainly is replaced by bone and fibrocartilage may be so

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Fibrous situation and age Another factor acting against bony union may be the dense fibrous situation in which the os lies which could

predispose to fibrous union One way in which this might happen is that by inserting into the shaft at various points the fibrous tissue is so firmly attached that the periosteal reaction is restricted Periosteal reaction might be limited because of little stimulation from tearing or because of the lack of space in which high bony trabeculae could grow The lesser callus formed on the dorsal surface of the shaft may in part reflect a firmer attachment of the periosteum there than to ventral surfaces

The periosteal reaction along the shaft sides was somewhat greater in the younger animals which may be related to the young periosteum s being less firmly attached to surrounding connective tissues Aho (1966) compared the repair of unstabilized tibial fractures in young and old rats and noted somewhat quicker and a little greater production of callus in younger animals In the penile bone the amount of callus produced is less in both young and old animals than in the tibia and no significant difference in callus volumes was apparent Moreover the penile fracture involved the shaft which even in these young animals was not growing very actively The bone actually broken may be relatively more mature than the base of the os and other growing zones of such young rats

The firmness with which the broken os remains attached to its fibrous surroundings and its lack of weight bearing may explain why fracture does not stimulate or prolong endochondral growth at the proximal base in the manner reported by Bisgard (1936) for the epiphyses of the growing goat s tibia when the shaft is broken

Cartilage in callus No matter where along the length of the shaft the cut or break came the events of fracture repair were the same and in particular cartilage cells were always present in the callus They occur in spite of the description by Ruth (1934) of the distal part of the shaft as originating without the prior formation of cartilage although no precise proportion of the shaft s length arising in this non endochondral way could be given

The hypothesis that bones developing intramembranously do not develop cartilage during fracture healing was disproved by Pritchard s (1946) solitary observation in a rat skull the fibrocartilage seen in healing fractures of the rat mandible by Sarnat & Schour (1944) and the cartilage and endochondral ossification noted by Richman & Laskin (1964) in one fourth of fractures involving the dog s zygomaxillary complex Scraping the skull before fracture makes cartilage more likely to form in infant rats because Girgis & Pritchard (1958) believe

the ischaemic environment thus produced favours the formation of cartilage Contact and compression between bone pieces (Eggers Shindler & Pomerat 1949) and vitamin A deficiency (*Beresford unpublished observation*) also promote the development of cartilage in healing rat parietal bones Factors existing or arising at the time of fracture may therefore prevail over any tendency of callus cells to form only bone because of their embryonic origin or associations

Epithelial bone induction Because of the well known osteogenic inductive power of urinary tract epithelium the greater development of callus on the urethral side of the os might be another manifestation of this phenomenon Several arguments are against such an induction s having taken place New bone and cartilage were always in continuity with the old bone and were separated by a substantial layer of connective tissue from the epithelium The urethral epithelium at this point is not transitional and has not been shown experimentally to have any osteogenic influence Finally the rat s urinary bladder epithelium regularly induces bone formation but the amount formed is very small in comparison with for example the guinea pig s (Beresford & Hancox 1967)

Bone in human phallus This investigation has no direct bearing on any orthopaedic problem involving bone in the human penis since bone and cartilage are an abnormality in man s phallus Eglitis (1953) reviewed five previous histologically confirmed reports of bone in the human penis and added another himself He drew attention to a number of considerations indicating that the bone s occurrence was a pathological event of the same nature as the formation of metaplastic bone in the connective tissue of many other organs of the body and was in no way to be construed as an atavistic attempt to form an os priapi of specific shape size and position such as other primates possess (Gerhardt 1910)

SUMMARY

Fractures of the shaft of the penile bone were made by severance or closed manipulation in 66 young and mature rats Healing was followed histologically for a period from 4 to 210 days after operation Union of the angulated bone pieces by bone or cartilage occurred in just over half the severed bones and in all 12 manual fractures Although six severed gaps 1 mm wide were bridged others of only ½ mm width remained un united in animals surviving for two weeks and longer

No clear difference in the volume of callus was noted between the

predispose to fibrous union One way in which this might happen is that, by inserting into the shaft at various points the fibrous tissue is so firmly attached that the periosteal reaction is restricted Periosteal reaction might be limited because of little stimulation from tearing or because of the lack of space in which high bony trabeculae could grow The lesser callus formed on the dorsal surface of the shaft may in part reflect a firmer attachment of the periosteum there than to ventral surfaces

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No clear difference in the volume of callus was noted between the

young and mature groups The callus was osteocartilaginous and of periosteal origin It formed mostly inside the angle on the ventral urethral sides of the shaft An internal callus was not *formed, probably* because the marrow cavity of the base does not extend along the shaft

The fibrocartilaginous interior process lying distal to the penile bone was found regularly to undergo some endochondral ossification unrelated to any fracture in the principal penile bone of these and 10 intact rats

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DIAGNOSTIC USE OF ^{85}STRONTIUM IN THE PREOPERATIVE EVALUATION OF NON UNION

G Segmüller O Cech & A Bekier

Received [illegible] 69

Bone grafting procedures have received universal acceptance in the treatment of non union (Phemister 1914 Lexer 1924 Albee 1930 Witt 1952 Merle d Aubigne 1959 Harris et al 1965 Compere et al 1966, Hanson & Eppright 1966 Lange 1967 Rogers 1968) Some diversity of opinion still exists as to the type of grafting material appropriate in a given case and to the best grafting technique (Boyd et al 1965 Rogers 1968) While bone grafting alone has been used ever since Lexer and Albee an increasing number of orthopaedic surgeons over the last 20 years have preferred a combination of bone grafting and internal fixation by metallic implants Standard bone plates were used at first then intramedullary nailing became a standard procedure for a number of pseudarthroses (Lambotte 1913 Kuentscher 1940/1954 Boyd et al 1965) Stabilization by external compression devices was favoured in France and in Switzerland (Hoffmann 1951 Greifensteiner 1953 Ricklin 1957 Mueller & Allgoewer 1958) Interfragmentary compression by a special plate was first used by Danis (1949) Many authors now use the AO compression plate designed by Mueller (1963) (Boyd et al 1965 Cech & Stryhal 1967)

Two main principles have always governed the treatment of non union (A) stabilization and (B) stimulation of osteogenetic activity

The first argument is of a biomechanical nature i e forces acting on the fragments should be eliminated to achieve full immobilization of the zone of disturbed fracture healing Remarkable progress has been made in recent years concerning firm and lasting stabilization of fragments by means of accurate intramedullary nailing and by the

correct application of compression plates (Mueller 1963 Mueller et al 1965 Segmueller 1966) Fixation provided by cortico cancellous grafts alone however must be supplemented by plaster casts Functional treatment and weight bearing is therefore not allowed though it would seem to be essential in the presence of already impaired function of the extremity

The second principle concerns *the pathophysiology of bone repair* at the fracture site The osteogenetic activity at the site of non union was always believed to be poor and an osteogenetic stimulus was therefore considered to be essential in the operative treatment of non union There is however little information about the actual osteogenetic activity of any given stage in the development of delayed union or non union

Judet has demonstrated the presence of extensive vascularization of the bone at the so called zone of sclerosis at the bone ends (Judet & Judet 1960 Judet et al 1958) The resection of the sclerotic bone ends advocated especially by German authors was no longer advised by Judet nor by Burrows (1940) Phemister (1947) and Delangeniere (1920) before him These authors were against the disturbance of the fibrous union of the fragments According to their findings intermediary fibro cartilagenous tissue would calcify readily upon application of a small subperiosteal bone graft and additional external fixation by plaster cast In experimental non union in the dog Schenk (1968) has shown that blood supply is abundant in the area surrounding non union and that numerous vascular sprouts approach the main line of pseudarthrosis very closely Rhinelander et al (1968) demonstrated an extremely dense vascular network in the callus surrounding delayed union of displaced fractures in dogs Trueta (1967/1968) in accordance with many previous workers pointed out the essential role of capillaries in the process of new bone formation It would therefore seem that biological conditions in the "usual type of clinical non union are rather favourable to new bone formation and that correction of the biomechanical factors alone could suffice for the requirements of normal bone repair In recent years much clinical evidence has been accumulated lending support to the assumption that operative stabilization without additional bone grafting leads to successful healing in many cases Infected non union as well as pseudarthroses with bone defects present additional problems and are not dealt with in this paper

In the preoperative evaluation of clinical non union a lack of infor

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Figure 1a

Figure 1b

Figure 1a Non union of tibia 18 months after open fracture Radiologically no increase of callus formation for the last 8 months

Figure 1b Colour scan 9 days following ^{85}Sr administration demonstrating marked increase of tracer uptake at the site of non union

has been done at 30 min 1 hr 2hrs (3 hrs) 24 hrs 48 hrs 96 hrs and 1 week following intravenous administration of the tracer Six anatomically corresponding locations over the tibia were chosen and their distances exactly measured The principle underlying this work is

mation about the osteogenetic capacity of the tissue at the site of non union is obvious This means that in addition to the conventional X ray pictures more information about the functional state of the bone repair process is needed The uptake of tracers such as ^{45}Ca and ^{85}Sr in human tibial and femoral fractures was studied by Bauer and Wendeberg in 1959 and 1961 (Wendeberg 1961 Bauer & Wendeberg 1959 Bauer & Ray 1958) They found a rapid uptake of ^{85}Sr in the fracture *region* during the first hour post injection This according to the authors indicates a rich blood supply to the fracture area and a rapid exchange of mineral salts between body fluids and callus Two weeks after injection of ^{85}Sr most of the isotope has been incorporated into the skeleton by actual accretion i e mineralization of osteoid matrix It is the purpose of this paper to make available for special problems in the clinic the experimental bone seeking tracer studies of Bauer & Wendeberg (1961) The clinical evaluation of osteogenetic activity in non union does not depend on absolute values of local mineral metabolism However the relative mineral accretion rates in areas of disturbed bone repair could well be used in determining the actual state of activity of osteogenetic tissue

External Counting Techniques Used in this Clinical Study

In this clinic ^{85}Sr ^{8} ^{m}Sr and ^{45}Ca are used as bone seeking tracers for diagnostic work up of patients with bone lesions Recording is done by scanning and external counting techniques Scanning has proved to be superior (both clinically and in preliminary investigations on a laboratory model simulating conditions in bone) for determinating the extent of the lesion When scanning is used alone ^{8} ^{m}Sr is preferred for its short half life External counting by scintillation detectors allows for repeated counting in the early equilibration phase as well as days or weeks thereafter In studying bone repair this is of great advantage Cylindrical collimators and conic collimators are not used in this investigation

A modified technique with the 1-inch scintillation detector has been tested and compared with other techniques In locations where the bone covering soft tissue layer is thin (lower legs) this technique permits essential dosage reduction of the tracer substance (5–10 μCi ^{85}Sr) and is therefore applicable in young patients A detailed description of the technique is in preparation

In this pilot study on osteogenetic activity in non union counting

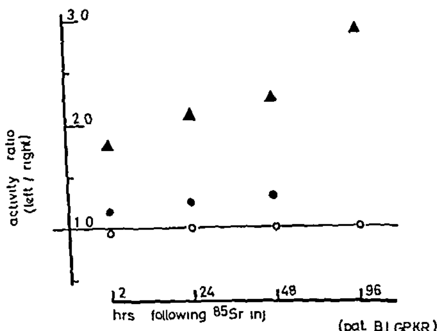


Figure 3 The activity ratio of 3 clinical cases with fracture of the lower leg

▲ Non union of left tibia (8 months after injury) Radioactivity is persistently high over the bone lesion the ratio therefore increases from 2 15–2 7 within 4 days
● Delayed union of left tibia (5 months following fracture) radiologically poor callus formation Radioactivity shows little increase compared with normal (ratio 1 15–1.3)
○ Fracture of left tibia (8 years prior to investigation) fully consolidated Activity ratio remains unchanged at unity (1 0 ± 0 05)

is almost at its maximum within the first three hours following injection The early rapid uptake of the bone seeking isotope can be well demonstrated by either method Colour photoscan with 85Sr or 87mSr and external counting by scintillation detector using 85Sr

In our experience there are marked differences of 85Sr uptake in different types of non union In Figure 3 the activity ratio (left/right tibia) of three cases is shown Case 1 (▲) represents a very active type of pseudarthrosis (Figure 4) 9 months following injury with an activity ratio of 2 15 at 2 hrs increasing to 2 7 four days following intravenous injection of 85Sr The X ray of Case 2 (●) is characterized by no callus formation at all (Figure 5) The activity rates however recorded at the site of non union still demonstrate a moderate increase

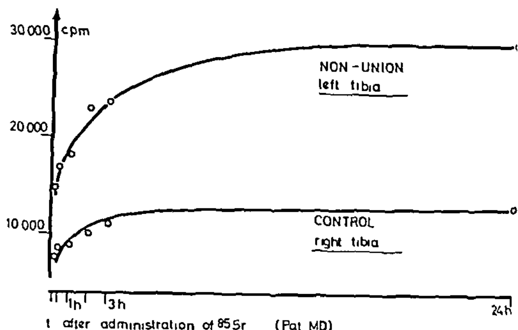


Figure 2 ^{85}*Sr uptake at the site of non union (9 months after fracture) of the left tibia and at the same location on the right tibia as point of reference First counting 15 min after intravenous administration of 13 μCi of* ^{85}*Sr The difference in uptake is at its maximum immediately following injection*

direct comparison of activity of the diseased extremity with the control side Therefore correction of counting rates for decay and comparison with standard samples are not considered necessary

CLINICAL CASES

In Figure 1 X ray and photoscan of a case of non union are presented Active callus formation is demonstrated by the conventional roentgenogram and a considerable early uptake of ^{85}Sr (colour scan) gives additional proof of greatly increased mineral metabolism at the site of disturbed bone repair This finding of early active ^{85}Sr (or C^{++}) exchange between body fluids and callus tissue reflects a large exchangeable calcium space on the basis of a rich blood supply to the site of non union This would be in accordance with the histological findings on experimental non unions (Judet & Judet 1960 Judet et al 1958 Schenk 1968 Rhinelander et al 1968)

The rapid tracer uptake in the very early phase of equilibration in the body fluids is also shown in Figure 2 The difference of the counting rate between diseased tibia and control tibia in the same individual

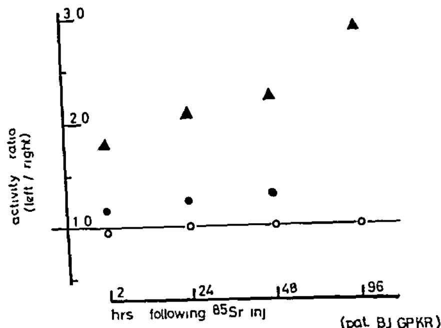


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Figure 4



Figure 5

Figure 4 X ray of Case ▲ in Figure 3 taken immediately after intramedullary nailing of non union Moderate callus formation 9 months after injury Uptake of ^{85}Sr at the site of the non union (Figure 3) however is high

Figure 5 X ray of 5 month old fracture shows little callus formation Tracer uptake slightly elevated is shown in Figure 3 Case ●

of ^{85}Sr uptake, compared with the control side No increase of tracer uptake is recorded in Case 3 (○) at the site of a healed lower leg fracture 8 years after injury (Figure 6) Activity ratio remains at unity in an early recording and also in late recordings



Figure 6 X ray of Case O in Figure 3 healed fracture 8 years after injury Bone remodelling seems to be complete No increase in tracer uptake.

DISCUSSION

Even though scintigraphic studies are not meant to give a quantitative answer to the question of local mineral metabolism of bone they clearly show a heavily increased local activity at the site of pseudarthrosis immediately after injection These findings point to the fact of a larger exchangeable calcium space at the site of disturbed bone healing as compared to the control side Such rapid local mineral exchange during an early equilibration phase is indicative of a rather rich local blood supply The marked increase in new bone formation expressed by the late activity ratio (non union/control side) allows the



Figure 4 | Figure 5

Figure 4. X-ray of Case ▲ in Figure 3 taken immediately after intramedullary nailing of non-union. Moderate callus formation 9 months after injury. Uptake of ^{85}Sr at the site of the non-union (Figure 3), however, is high.
Figure 5. X-ray of 5 month old fracture shows little callus formation. Tracer uptake slightly elevated as is shown in Figure 3. Case ●

of ^{85}Sr uptake compared with the control side. No increase of tracer uptake is recorded in Case 3 (○) at the site of a healed lower leg fracture 8 years after injury (Figure 6). Activity ratio remains at unity in an early recording and also in late recordings.

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assumption that local osteogenetic capacity is not lost but increased. As Bauer pointed out, this gives no right to assume that fracture healing will therefore occur. The rate of local bone resorption *might be as* active as new bone formation, which means that there would be no net gain of new bone tissue at all. However, as discussed earlier, clinically we are interested in the actual osteogenetic capacity of the tissue rather than in quantitation of new bone formation in order to answer the long standing question of whether the fibro-cartilaginous "scar tissue" of the non-union is of so-called poor quality.

In our present clinical investigation we have been impressed by the fact that in different types of non-union remarkable differences in ^{85}Sr uptake are recorded. In Figure 3, two of our cases are presented demonstrating clearly the range of difference in tracer uptake at the fracture site. The recordings of the clinical cases investigated in our study lie between these extreme values of a case of maximum increase and one of slight increase in radioactivity. We therefore consider the external ^{85}Sr counting technique a valuable parameter in the preoperative evaluation of the functional state of pseudarthrosis. As a diagnostic procedure this technique provides the clinician with a more rational approach to the question of whether he has to deal with poor osteogenesis or whether the only aetiological factor of non-consolidation in any given case is merely a mechanical one.

SUMMARY

The clinical evaluation and classification of non-union of long bones is generally based on conventional roentgenograms. The questions of the local vascularization and the new bone forming capacity of the intermediary fibro-cartilaginous tissue is not answered by this source of information. By means of early photoscanning and/or early external counting technique as well as late external counting of ^{85}Sr with the aid of a scintillation detector, we have a parameter of local mineral metabolism for the evaluation of local osteogenetic capacity of non-union.

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RECURRENT DISLOCATION OF THE SHOULDER TREATED BY TRANSPOSITION OF THE TENDON TO PECTORALIS MINOR

A Follow Up of Fifteen Patients

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Received 11 68

Recurrent dislocation of the shoulder is practically always a forward dislocation but may occasionally be backward Distinction is made between a traumatic type and one of unknown cause In the former type there is an adequate trauma as cause but this is not always so in the latter type The transition between the two types is fluid as the trauma may be very mild so it is reasonable to ask in these cases too whether there was a disposition for dislocation This reservation should be borne in mind when it is stated that 94 per cent of all cases are of the traumatic type (Rowe 1962)

In these cases the cause is an injury to the joint capsule and/or joint head at the first dislocation The glenoid lip may be torn from the anterior border of the glenoid cavity or there may be a defect in the joint capsule which does not heal or there may be a defect at the back of the head of the humerus

In the second type the picture is marked by a slack joint capsule or weak shoulder musculature

After a while dislocation may arise on only slight trauma or from special movements of the shoulder joint such as putting on a coat swimming throwing etc and external rotation in particular produces dislocation A number of operations such as Bankart s operation Putti Platt s operation Magnuson and Stack s operation and Gallie Le Mesurier s operation are based on limiting the capacity of the shoulder joint for external rotation The incidence of relapse following these operations is said to be under 7 per cent (Cave 1958)

Several of these methods are regarded as being technically rather

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fixed address Thus 15 patients were followed up Their age and sex distribution is shown in Table 1

Table 1

	Men	Women
Under 20 years	1	1
20–50 years	6	4
Over 50 years	2	1
Total	9	6

Three had heavy physical work, 6 had office work or were students, 4 were house wives, and two were not working for causes other than their shoulder disorder

All 9 men and 4 women must be reckoned to have had habitual dislocation of the shoulder of the traumatic type whilst an *11 year-old girl* had *weak musculature* and unilateral dislocation and a 32 year old woman had bilateral dislocation with*out definite preceding trauma* She was operated on only one side. All patients had had repeated dislocations and clinical histories lasting from 46 years to 5 months.

Apart from the 11 year old girl forward dislocation occurred in each case

There were no complications following any of the operations. Follow up took place after 1–6 years In the majority of cases this was carried out by means of a questionnaire which was filled out by the patients Six of the patients had had dislocation after the operation Four reported that they had had only one disloca*tion and with minimal trauma* One had had a *dislocation* while *lying in* bed two years after her operation Another was sitting when the shoulder dislocated The two who had several dislocations after the operation also said that they had resulted from small injuries One of them had the first relapse in association with a ski fall. One patient was well for 5 years after operation before she dislocated again The two with repeated *dislocations* were a 23 year old woman architect and a 53 year-old man who had a disability pension for reasons other than his shoulder condition and did not work. Of the 9 who had not had *any relapse*, 3 were not very satisfied because they had limited movement and pains after work or they felt that the arm was weaker than before operation

CONCLUSION

The operation for habitual shoulder dislocation reported by Dickson & O Dell in which the tendon of pectoralis minor is transferred to the humerus is technically simple but 2 of 15 patients had repeated re dislocations and 4 had single relapses The material is too small to draw any conclusions as to whether there are special conditions which predispose to re dislocation but age sex and nature of work do not seem to have any significance

laborious Dickson & O'Dell (1952) introduced an operation in 1952 which was technically easier From phylogenetic studies in apes and investigations on human foetuses, they found that the internal rotators of the upper arm were gradually weakened in relation to the external rotators Originally, pectoralis major and pectoralis minor were together as one common muscle which attached to the humerus or pectoralis minor could be found as an independent muscle attached together with pectoralis major on the humerus Dickson & O'Dell believed that by moving the attachment of the pectoralis minor from the coracoid process to the humerus they would convert the muscle into an internal rotator and thus achieve the muscle balance which these patients lacked The stability of the shoulder joint would thus be increased They also reported that Seib (1938) on dissection of 1 000 shoulders found that pectoralis minor deviated from its attachment to the coracoid process in 15 per cent and that in 1 per cent it was attached to the humerus

The operation is carried out by making the incision in the deltoid pectoralis sulcus The tendon of pectoralis minor is dissected free and separated from the coracoid process by chipping a small splinter of bone from the process A non absorbable suture is attached to the tendon which is then freed so that it can be transferred to its new position without difficulty Immediately proximal to the tendon of pectoralis major an opening is chiselled in the cortex of the humerus shaft just big enough to allow the bone splinter from the coracoid process to be passed through The suture in the pectoralis minor tendon is led out through two boreholes lateral to the chiselled trap door and knotted The pectoralis minor tendon is fixed to the major tendon with a few sutures Internal rotation makes it easier to draw the pectoralis minor tendon into place and fix it After closing the wound the arm is immobilized with a Velpeau bandage for 4 weeks and there after placed in a sling for a further 4–8 weeks At this time the patient starts active exercises with the arm Forcing of external rotation should be avoided Complete rehabilitation is generally achieved in the course of 8–12 weeks after operation

PERSONAL MATERIAL

Material from Martina Hansen's Hospital and Rigshospital Surgical Department B has been studied in order to get an impression of what this operation can offer In all 17 patients were operated by this method in the course of 1961–1967 Two patients could not be contacted as one had left the country and the other had no

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VERTEBRAL ANGIOSARCOMA

A Case Report

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Angiosarcoma (syn malignant hemangioendothelioma) of bone especially of the vertebrae is a rare neoplasm Bundens et al (1965) reviewed 32 well documented cases of bone angiosarcoma out of which only 3 appeared in the spine Ackerman et al (1962) De Rubertis et al (1967) and Krueger et al (1961) reported 4 additional cases

Since the tumour is rare it might be justified to report one more case of vertebral angiosarcoma to demonstrate the dramatic course of the disease

CASE REPORTS

A 19 year old female typist was admitted to the Department of Orthopaedics and Traumatology of the University Central Hospital Helsinki for examination. For over a month she had experienced pain between the scapulae and in the shoulders for two days before admission she had found it difficult to walk and the pain had expanded to the lumbar area She was unable to defecate and micturate The day previous to admission she was bedfast because of immobility of the right leg She complained of severe throbbing pain in the back at the level of the lumbar spine and on both sides of the chest when any effort to move was made. She experienced a tingling sensation in the chest wall and right hand and was unable to laugh or cough.

On arrival at the hospital the right leg was completely flaccid the patient was unable to lift the leg or to move the toes or the foot The Lasegue sign was positive at 75 The patellar and achilles tendon reflexes of the right leg were active, no clonus. The Babinski sign was negative The entire area of the right lower extremity and the right side of the abdomen were hypersensitive The left leg had normal strength. The Babinski sign was negative The other reflexes were medium active the Lasegue sign was positive at 45 The pulses and the skin temperatures of the legs were normal In the area of TII on the back an extremely tender tumour about 6–7 cm in diameter was palpable.

About 12 hours after admission a total paralysis had developed below the level of the 4th rib and the reflexes were completely lacking. There was an anaesthetic

SUMMARY

The author reports a material of 17 patients who were operated for recurrent shoulder dislocation by transposition of the attachment of the pectoralis minor from the coracoid process to the humerus as reported by Dickson & O Dell

Fifteen of these patients were successfully contacted by means of a questionnaire Four had had an isolated recurrence after operation and two had had repeated re dislocations

Of the 9 who had not had a recurrence after operation, 3 were dissatisfied because of pain in the operated shoulder and because the arm felt weaker than before the operation

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Longitudinal incision through the layers of tissue over the area of TI–TII revealed a fluctuating tumour about 7 cm in diameter which was partly formed of a necrotic mass and blood. After removal of the tumour tissue engorged with blood was found in the bottom of the cavity. The tumour was located in a region corresponding to the right spinal arch and spinous process of TII which were completely destroyed. The left spinal arch had also been destroyed to some extent. Similar changes were present in the right pedicle and the vertebral body. The bone was bleeding profusely and could only be staunched with bone wax with difficulty. The tumour was so extensive that radical extirpation was impossible. The exposed dura mater in the bottom of the cavity was apparently intact although compressed by haematoma. Biopsies were taken from the tumour. A suction drainage was placed and the wound closed. The neurological state remained unchanged after the operation. The patient died suddenly on the 4th postoperative day. The autopsy revealed a primary malignant tumour of vascular origin which had destroyed its surroundings. Extradural haematoma had extended to the cervical spine and had compressed the medulla all the way to the respiratory centre. It was concluded that the patient died from a respiratory arrest.

The pathological diagnosis was angiosarcoma (*Figure 3*). The characteristic features were abundant anastomosing blood filled tubes lined with proliferating atypical cells of endothelial origin which infiltrated the surroundings including the bone. At some places the neoplastic tissue revealed sarcomatous make up and papillary formations.

DISCUSSION

In his paper on angiosarcoma Stout (1943) describes the condition as a neoplasm made up of congeries of vascular tubes which have a marked tendency to anastomose and are lined with hyperchromatic tumour cells of endothelial origin. Jaffe (1958) and Leichtenstein (1965) agree that angiosarcoma is practically impossible to diagnose clinically, i.e. without an operation and subsequent histologic examination of biopsies. The case presented here shows features indicating according to the above authors that the tumour is an angiosarcoma. This case closely resembles that reported by Krueger *et al* (1961). In both instances the patients were young adults who revealed similar subjective symptoms and clinical signs. The location of the tumour was almost the same in both cases.

As for the treatment of angiosarcoma when diagnosed most authors (Bundens *et al* 1965, Carter *et al* 1956, Jaffe 1958, Krueger *et al* 1961, Lichtenstein 1965) recommend primarily radical surgery whenever possible combined with massive postoperative X-ray irradiation. Morgenstern (1960) on the other hand reports a case of angiosarcoma of the clavicle cured with irradiation only and recommends radiation as the sole treatment.

The prognosis of angiosarcoma is poor for several reasons. Out of



Figure 1



Figure 2

Figure 1 Roentgenogram Destruction of spinous process in TII
Figure 2 Tomogram Cyst like formation on the right side in vertebral body of TII

Figure 3 Microphotograph Anastomosing vessels and abundant atypical cells of endothelial origin Magnification × 250 Weigert—Van Gieson staining

area extending caudally from the 4th rib over all segments X ray examination (Figure 1) revealed a destruction of the lamina and a partial destruction of the spinous process of TII The tomogram (Figure 2) showed the presence of a round opaque area about 2 cm in diameter in the vertebral body and a destruction of the right half of the spinal arch and spinous process of TII Since paralysis had developed rapidly and was complete an immediate operation was performed

Longitudinal incision through the layers of tissue over the area of TI-TII revealed a fluctuating tumour about 7 cm in diameter which was partly formed of a necrotic mass and blood After removal of the tumour tissue engorged with blood was found in the bottom of the cavity The tumour was located in a region corresponding to the right spinal arch *and spinous process of TII* which were *completely destroyed* The left spinal arch had also been destroyed to some extent Similar changes were present in the right pedicle and the vertebral body The bone was bleeding profusely and could only be staunched with bone wax with difficulty The tumour was so extensive that radical extirpation was impossible The exposed dura mater in the bottom of the cavity *was apparently intact although* compressed *by haematoma Biopsies were taken from* the tumour A suction drainage was placed and the wound closed The neurological state remained unchanged after the operation The patient died suddenly on the 4th postoperative day The autopsy revealed a primary malignant tumour of vascular origin which had destroyed its surroundings. Extradural haematoma had extended to the cervical spine *and had compressed the medulla all the way to the respiratory centre* It was concluded that the patient died from a respiratory arrest

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The prognosis of angiosarcoma is poor for several reasons Out of

the 32 cases reviewed by Bundens *et al* (1965) only 9 *were known* to have survived until the time of reporting the cases however none had an angiosarcoma of the vertebrae There is only one case of vertebral angiosarcoma in the literature (Krueger *et al* 1961) where the patient was known to be alive 2 years postoperatively Since the disease in the present case was already so far advanced by the time of admission to the hospital that a beneficial radical operation was *impossible* a decompressive measure was taken Because the case quickly terminated fatally no irradiation treatment could be started

SUMMARY

A case of vertebral angiosarcoma (malignant hemangioendothelioma) is presented Only 7 cases of this type have been reported earlier The case involves a 19 year old female with a histologically verified angiosarcoma of vertebra TII The compression of the medulla caused by profuse extradural bleeding of the tumour was lethal

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ROENTGEN APPEARANCE OF COXARTHROSIS

Relation between the Anatomy Pathologic Changes and Roentgen Appearance

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Received 5 xi 69

Though it is known that *osteophytes are reactive changes secondary to* cartilaginous degeneration roentgenographically demonstrable osteophytes in the hip joint sometimes persist unchanged for a long time without any associated clear differences in the joint space i e without cartilaginous changes A frequent moot point is whether such lesions should be regarded as manifestations of aging or of arthrosis

As soon as subchondral changes supervene however the condition must undoubtedly be diagnosed as coxarthrosis In such cases the joint cartilage is as a rule more or less destroyed by local relative *overloading of the degenerated cartilage*

The destruction usually involves the proximal part of the femoral head and the corresponding part of the acetabulum

The distribution of the load on the hip thus plays an important role in coxarthrosis As in a previous investigation (Hermodsson 1947) the anatomy of the joint was therefore judged from the size of the CE angle which allows a good conception of the distribution of the load on the hip

The subchondral changes formerly widely regarded as a manifestation of ischaemic necrosis have long been known *to pathologists The* modern consensus of opinion however recognises two phases *vi* a productive and a destructive one

The Productive Phase

In this phase the subchondral bone becomes hyperaemic and hyper

The investigations were aided by a grant from Thorsten and Elsa Segerfalks Foundation Helsingborg

vascular in response to a stimulus from the degenerating joint cartilage in the so called pressure area of the proximal articular surface of the femoral head. New bone forms round the vessel walls in the weight bearing segment of the head with consequent bone sclerosis. The hyperaemic reaction, however, reduces the resistance because the bony architecture gradually becomes rarefied and weakened.

The Destructive Phase

In this phase the excessive pressure on the proximal part of the femoral head results in total local destruction of the cartilage and the repair processes in the joint cartilage and the subchondral bone fail to revitalize (regenerate) the tissue. The result is necrosis, so called cyst formation, collapse of a varying sized part of the bone with flattening of the overlying surface and upward lateral displacement of the femoral head. The displacement results in medial widening of the joint space. This is accompanied by the development of osteophytes in the joint cartilage on the medial articular surface of the femoral head, i.e. in the non pressure area. Marginal osteophytes develop on the head, neck and acetabulum during both of these phases.

Recent descriptions of the pathologic anatomy of advanced coxarthrosis agree well with the roentgen appearance of the type of changes here called proximal arthrosis.

ROENTGEN APPEARANCE OF COXARTHROSIS

A. *Signs of Degeneration and Destruction of the Cartilage*

Since the only direct sign of degeneration of the cartilage in the roentgenogram is a decrease in the volume of the joint cartilage, which is reflected mainly in a narrowing of the joint space, it is understandable that mild degeneration of the cartilage is not demonstrable roentgenographically. Moreover, no joint space will be seen in the medial part of the hip joint. (The thickness of the basal calcified zone of the joint cartilage may deviate from normal. The occurrence and significance of such a deviation will not be discussed here.)

It should, however, be recollected that a decrease in the width of part of a joint space implies a displacement of the corresponding part of femoral head towards the acetabulum. Since the hip joint is a ball and socket joint (enarthrosis), such displacement is usually accompanied by an increase in the width of other parts of the joint space

Cartilaginous destruction may also be manifest as a change in the floor distance (see D Displacement of femoral head)

B *Osteophytes*

According to modern pathologists secondary bone formations osteo phytes are less important than previously supposed It should also be borne in mind that in degeneration of the cartilage osteophytes constitute only a local reaction and not a referred reaction In this conjunction it might not be out of place to mention Harrison & Trueta s (1953) remark The osteophyte is the result of an attempt to revitalise degenerating cartilage and mark the site of a biological response to a tissue sick from underwork

Osteophytes are however the most characteristic and striking roentgenologic changes of arthrosis It is therefore natural that they have received such wide attention in the roentgenological diagnosis and literature

Osteophytes on the femoral head and neck fall into four types marginal perifoveal buttress (Wiberg 1939) in the dorso medial part of the femoral neck and capital drop

The term capital drop coined by Waldenstrom & Wiberg is hardly adequate because the bone formations in question manifest themselves not only as drop shaped marginal osteophytes but usually also extend far up onto the medial articular surface of the femoral head the non pressure area in the form of a deep seated layer in the uncalcified part of the articular cartilage The blood vessels responsible for these bone formations spring from marginal vessels and from newly *formed* vessels coming from the subchondral bone and piercing the otherwise largely preserved basal calcified zone of the articular cartilage

The outline of this calcified zone represents the roentgenologic outline of the head and it appears in the same unchanged position irrespective of any osteophytes in the uncalcified articular cartilage The appearance of the roentgenogram often conveys the impression of a *double joint* surface This phenomenon and the underlying pathological changes were described as early as 1934 by Hermodsson *in an* investigation of dislocations of the shoulder joint

Five types of osteophytes can be recognized on the acetabulum (A) on the upper lateral border (B) on the lower border of the *posterior* horn (C) along the anterior border of the posterior horn (D) double acetabular floor and (E) *along the lateral* border of the os ileum outside and above the upper lateral *margin* of the acetabulum in some

cases of proximal arthrosis with marked displacement of the head. They seem to lengthen the roof of the acetabulum laterally and are therefore here referred to as "eaves". (They correspond largely to what is generally called "Vordach" in the German literature.)

C. *Structural Changes*

These radiologic changes, which are most marked in the femoral head, occur mainly in the second stage, the destructive phase of the bone changes. The pathologic-anatomic picture is clearly reflected in the roentgenogram.

In the productive phase the structure as well as the calcium of the spongy bone may appear somewhat irregular. Rarefied areas alternate with denser areas leaving the impression of sclerosis. These changes are most common near the articular surface and are confined to areas beneath roentgenologically demonstrable destruction of the cartilage.

In the destructive phase the structure of the spongy bone appears more or less indistinct. Cystic formations, sometimes with dense margins, may be seen.

In advanced arthrosis with widespread structural changes large parts of the femoral head as well as corresponding parts of the acetabulum successively collapse and become flattened. The consequent deformation of the head can be readily differentiated from the deformation by osteophytes by examination of the basal calcified zone in the articular cartilage. This zone is more or less well preserved in cases with capital drop and is always situated at its original site. But in cases of collapse and flattening the roentgenogram shows no zone of calcium within the flattened part.

The structural changes described above are seen mainly in proximal arthrosis. Therefore, and in agreement with descriptions by pathologists, it is mainly in the upper proximal part of the hip joint that such features are seen in the roentgenogram.

D. *Displacement of Femoral Head*

1. Cartilaginous destruction implies, as pointed out above, a displacement of the femoral head and this displacement may be manifest by a decrease or an increase of part of the roentgenologically visible joint space. Consequently an increase does not necessarily mean a true increase in the thickness of the articular cartilage. Misinterpretations in this respect are not rare.

2 In the medial part of the hip joint there is no roentgenologically demonstrable joint space but other signs of cartilaginous destruction can be seen The author coined the term floor distance to denote the shortest distance between the original surface of the femoral head and the outer limb of the so-called U figure or tear figure The original surface of the femoral head is to be understood here as the outline of the basal calcified zone of the articular cartilage

As described previously (Hermodsson 1947) the floor distance in non arthritic joints is usually 7–12 mm This range of variation may appear wide (but hardly when compared with the variation of the thickness of the articular cartilage) but in proximal arthrosis the floor distance is often substantially increased not infrequently two or more times the maximum normal distance On the other hand in medial arthrosis the distance may be abnormally short Such shortening is best seen on comparison between roentgenograms obtained in successive stages of arthrosis in individual cases

3 In many cases of proximal arthrosis Shenton s (Menard s) line is broken because the head is displaced in a proximal direction On the other hand in severe medial arthrosis there is sometimes a slight displacement of the head in a distal direction

4 Double acetabular floor and capital drop are signs of a displacement of the head They occur only in proximal arthrosis and may be regarded as a sort of vacuum phenomenon

5 Eaves (see above)

6 In certain advanced cases of medial arthrosis with severe widening of the lateral part of the joint space owing to medial displacement of the head osteophytes may be seen on the lateral part of the acetabulum on the lateral circumference of the neck and on the lateral articular surface of the head The last mentioned ones correspond to the osteophytes on the medial surface of the joint in capital drop in proximal arthrosis

7 The actual collapse flattening of a fairly substantial part of the head and acetabulum as is often found in proximal arthrosis implies a displacement of the head In advanced cases this displacement is much larger than that caused by changes of the joint space

8 A secondary acetabular protrusion may sometimes be seen in advanced medial arthrosis

I *Registration of the Roentgenological Changes*

CΓ angle is given in degrees

cases of proximal arthrosis with marked displacement of the head They seem to lengthen the roof of the acetabulum laterally and are therefore here referred to as eaves (They correspond largely to what is generally called Vordach in the German literature)

C *Structural Changes*

These radiologic changes which are most marked in the femoral head occur mainly in the second stage, the destructive phase of the bone changes The pathologic anatomic picture is clearly reflected in the roentgenogram

In the productive phase the structure as well as the calcium of the spongy bone may appear somewhat irregular Rarefied areas alternate with denser areas leaving the impression of sclerosis These changes are most common near the articular surface and are confined to areas beneath roentgenologically demonstrable destruction of the cartilage

In the destructive phase the structure of the spongy bone appears more or less indistinct Cystic formations sometimes with dense margins may be seen

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The structural changes described above are seen mainly in proximal arthrosis Therefore and in agreement with descriptions by pathologists it is mainly in the upper proximal part of the hip joint that such features are seen in the roentgenogram

D *Displacement of Femoral Head*

1 Cartilaginous destruction implies as pointed out above a displacement of the femoral head and this displacement may be manifest by a decrease or an increase of part of the roentgenologically visible joint space Consequently, an increase does not necessarily mean a true increase in the thickness of the articular cartilage Misinterpretations in this respect are not rare

gram the condition may be interpreted as moderate arthrosis stage II

As the arthrosis advances it produces roentgenographic signs of collapse flattening of the head and acetabulum The collapse of the roof is usually most pronounced laterally In the femoral head it is most pronounced in the antero-superolateral part (importance of lateral views) It is of interest to compare this collapse of the head with the *localization and development* of double acetabular floor and capital drop

Collapse of frequently considerable parts often causes sub tantial displacment of the head The most important roentgenological signs of this displacement are large increase of the floor distance double acetabular floor and capital drop Cases with these signs of proximal arthrosis may be labelled as severe stage III

CE Angle

In proximal arthrosis the CE angle is always subnormal (with 26° as the lower limit of the normal range)

It is however often difficult or impossible to assess the size of the CE angle in moderate and severe proximal arthrosis This had led to much confusion and many misinterpretations in the literature

When the head is displaced the displacement is usually craniolateral i e towards the upper lateral border of the acetabulum The centre of the head C thus shifts towards E If C follows the line CE exactly no true changes of the CE angle will occur But if the displacement occurs in a more sagittal direction thus steeper than the line CE the CE angle will tend to increase In the same way the CE angle will decrease if the direction of displacement of the head is less steep than the line CE The latter type of displacement is by far the more common

Evaluation of the true original CE angle in a given case of proximal arthrosis thus has several inherent sources of error

Point E is defined by Wiberg as follows the point where the curving of the acetabular border latero superiorly begins i e where the bony support may be considered to end The part of the acetabular roof *which gives a dense shadow in the roentgen* picture ends there

The true point E can however be blurred or effaced by the following changes

1 The density of the marginal zone lateral to E may be increased even in the mildest of the three stages of proximal arthrosis The distinct border between the true dense acetabular outline and the outline of the bone lateral thereto thereby disappears

p arthrosis of proximal type
m arthrosis of medial type
d floor distance (in mm)
cd cartilaginous destruction
o marginal osteophytes
bu buttress
dr capital drop
ca caves
str structural changes
cy isolated cysts
irr anatomical irregularities in the roof of joints with CE angles of normal size
pro secondary acetabular protrusion
cv coxa vara
ep inveterate epiphyseal slipping

If the *degree* of cartilage destruction is to be recorded, the symbols cd^{+}, cd^{++} or cd^{+++} may be used. A case of proximal arthrosis may be expressed, e.g., as follows: 12 p (cd+o+str+db), d = 24. A medial arthrosis, e.g. 35 m (o+cd), d = 1, irr, cv 115°.

PROXIMAL ARTHROSIS

The earliest sign of proximal arthrosis is usually a narrowing of part of the joint space as seen in the roentgenogram proximally in the joint, thus in the region of the roof. This is an expression of destruction of the cartilage there. This destruction is usually most severe laterally, in the region of I, but in some cases with only mild dysplasia the decrease in the width of the joint space is more distinct further medially (see below).

Small marginal osteophytes appear relatively soon.

The roentgenographic signs produced by these changes represent a mild form, stage I, of proximal arthrosis.

When destruction of the proximal cartilage advances and the destruction is more or less complete in a varying sized area, structural changes arise in the corresponding part of the femoral head and acetabulum. Isolated cysts, often with dense margins, are common, particularly in the roof. The floor distance is usually increased. The neck often shows a buttress, most marked on the dorso-medial circumference.

When structural changes are clearly demonstrable in the roentgeno

ram the condition may be interpreted as moderate arthrosis stage II

As the arthrosis advances it produces roentgenographic signs of collapse flattening of the head and acetabulum The collapse of the roof is usually most pronounced laterally In the femoral head it is most pronounced in the antero superolateral part (importance of lateral views) It is of interest to compare this collapse of the head with the localization and development of double acetabular floor and capital drop

Collapse of frequently considerable parts often causes substantial displacment of the head The most important roentgenological signs of this displacement are large increase of the floor distance double acetabular floor and capital drop Cases with these signs of proximal arthrosis may be labelled as severe stage III

CE Angle

In proximal arthrosis the CE angle is always subnormal (with 26 as the lower limit of the normal range)

It is however often difficult or impossible to assess the size of the CE angle in moderate and severe proximal arthrosis This had led to much confusion and many misinterpretations in the literature

When the head is displaced the displacement is usually cranio lateral i e towards the upper lateral border of the acetabulum The centre of the head C thus shifts towards E If C follows the line CE exactly no true changes of the CE angle will occur But if the displacement occurs in a more sagittal direction thus steeper than the line CE, the CE angle will tend to increase In the same way the CE angle will decrease if the direction of displacement of the head is less steep than the line CE The latter type of displacement is by far the more common

Evaluation of the true original CE angle in a given case of proximal arthrosis thus has several inherent sources of error

Point E is defined by Wiberg as follows the point where the curving of the acetabular border latero-superiorly begins i e where the bony support may be considered to end The part of the acetabular roof which gives a dense shadow in the roentgen picture ends there

The true point E can however be blurred or effaced by the following changes

1 The density of the marginal zone lateral to E may be increased even in the mildest of the three stages of proximal arthrosis The distinct border between the true dense acetabular outline and the outline of the bone lateral thereto thereby disappears

p arthrosis of proximal type
m arthrosis of medial type
d floor distance (in mm)
cd cartilaginous destruction
o marginal osteophytes
bu buttress
dr capital drop
ea eaves
str structural changes
cy isolated cysts
irr anatomical irregularities in the roof of joints with CE angles of normal size
pro secondary acetabular protrusion
cv coxa vara
ep inveterate epiphyseal slipping

If the *degree* of cartilage destruction is to be recorded, the symbols cd+ cd++ or cd+++ may be used A case of proximal arthrosis may be expressed e g, as follows 12 p (cd+o+str+db) d = 24 A medial arthrosis e g 35° m (o+cd) d = 4 irr cv 115

PROXIMAL ARTHROSIS

The earliest sign of proximal arthrosis is usually a narrowing of part of the joint space as seen in the roentgenogram proximally in the joint thus in the region of the roof as an expression of destruction of the cartilage there This destruction is usually most severe laterally in the region of L but in some cases with only mild dysplasia the decrease in the width of the joint space is more distinct further medially (see below)

Small marginal osteophytes appear relatively soon

The roentgenographic signs produced by these changes represent a mild form stage I of proximal arthrosis

When destruction of the proximal cartilage advances and the destruction is more or less complete in a varying sized area structural changes arise in the corresponding part of the femoral head and acetabulum Isolated cysts often with dense margins are common particularly in the roof The floor distance is usually increased The neck often shows a buttress most marked on the dorso medial circumference

When structural changes are clearly demonstrable in the roentgeno

greater A search of the literature failed to reveal any systematic analysis of the roentgenological differential diagnosis between arthritis and arthrosis of the hip This point is receiving attention by the author A detailed discussion of this differential diagnosis lies beyond the scope of this paper

CASES OF PROXIMAL ARTHROSIS



F j e 1 F I fen al 1936



Figure 2 Same patient 1936



Figure 3 Same patient 1939



Figure 4 Same patient 1939 Lauenstein's position

2 The point where the curving of the acetabular border latero superiorly begins is displaced further laterally owing to a slight flattening of the bone contour in this region in association with the increase of density (It should be observed that in many joints with a dysplastic acetabulum point L is situated far medially to the lateral border of the ilium

Thus, in the presence of arthrotic changes one might be misled to imagine that L is situated further laterally i e nearer the border of the ileum, than it really is This results in over estimation of the CL angle and the joint may be erroneously regarded as normal Several examples of such misinterpretations are on record

3 Because of collapse flattening of the bone above the acetabulum the visible outline of the roof may be situated further proximally than it was originally especially the lateral part Strictly speaking point E then no longer exists (Shenton s line is broken in such cases)

4 Eaves often elongate the outline of the roof laterally in such a way as to leave the impression that point E is situated much further laterally than it really is

A group of cases deserving special mention are joints with a CE angle 21–25°, corresponding to Wiberg s uncertain group These borderline cases often show a characteristic feature in the development of arthrosis which is due to the anatomic conditions

The slope of the acetabular roof in such cases is usually only slight and the radius of its curvature differs only slightly from normal The joint space is however narrowest medially (before arthrosis) as it usually is in dysplasia Destruction of the cartilage is usually not so preponderantly lateral as in pronouncedly dysplastic joints but more evenly distributed over the major part of the roof This is due to the difference in the distribution of the pressure The head is therefore displaced in a more cranial direction than in severe dysplastic joints

In mild proximal arthrosis the decrease in the roentgenographic width of the joint space may sometimes be most distinct in the medial part of the roof because of the above mentioned incongruence between the head and the acetabulum even if it is evenly distributed over the entire roof

This may be misleading and result in a diagnosis of medial arthrosis Proper analysis and evaluation of certain cases of this type is only possible if the development of the arthrosis has been followed preferably from the very beginning

The risk of misinterpretating such a case as mild arthritis is still

greater. A search of the literature failed to reveal any systematic analysis of the roentgenological differential diagnosis between arthritis and arthrosis of the hip. This point is receiving attention by the author. A detailed discussion of this differential diagnosis lies beyond the scope of this paper.

CASES OF PROXIMAL ARTHROSIS



Figure 1 F L female 1965

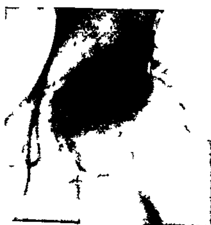


Figure 2 Same patient 1967



Figure 3 Same patient 1969



Figure 4 Same patient 1969
In Lauenstein's position

CASES OF PROXIMAL ARTHROSIS



Figure 5 B B female 1962



Figure 6 Same patient 1967



Figure 7 I W female 1959
Right hip joint



Figure 8 Same patient 1959
Left hip joint

CASES OF PROXIMAL ARTHROSIS



Figure 9 Same patient, 1968
Right hip joint



Figure 10 Same patient 1968
Left hip joint

MEDIAL ARTHROSIS

The roentgenogram of medial arthrosis differs strikingly from that of proximal arthrosis not only because of differences in type of roentgenographic details but also and perhaps mainly because of differences in the severity of the changes the lesions usually being more or less marked in proximal arthrosis but relatively few and mild in most cases of medial arthrosis

1 Judging from personal experience the first roentgenologic sign of medial arthrosis is small marginal osteophytes on the border between the femoral head and the neck on the border of the fovea on the upper lateral border of the acetabulum and on the *posterior horn* of the lunate surface

*Pathological studies have shown that the osteophytes are manifes*tations of a local reactive phenomenon seen in degeneration of the cartilage *Such degeneration* must therefore be present also in joints with roentgenographically demonstrable osteophytes but without any distinct narrowing of the joint space or shortening of the floor distance

2 However roentgenologic signs of the usually mild destruction of the cartilage in the medial part of the joint can be discerned with time

The decrease in the volume of the cartilage owing to destruction there reduces the floor distance This decrease which is often very small is best readily seen in those cases where the progression of the arthrosis can be followed

Owing to the anatomy (ball and socket joint) a decrease in the thickness of the cartilage medially with consequent, though only slight displacement of the femoral head in medial direction must also cause a slight decrease in the width of the most medial part of the joint space adjacent to the acetabular fossa Otherwise no medial displacement can occur unless the head is simultaneously displaced somewhat in distal direction as it occasionally is

The last mentioned phenomenon with displacement of the head medially inferiorly with demonstrable increase in width of the joint space in the entire region of the roof is here called a paradoxical increase in width because it is not a sign of an increase in the volume of the cartilage but of a decrease of the joint cartilage (thus a remote symptom)

Owing to the anatomy of the joint even the above slight decrease in the width of the medial part of the joint space produces a more or less distinct though slight increase in the width of the lateral part of the roentgenologic joint space These changes result in asymmetry of the joint space which is sometimes the most distinct radiologic sign of mild destruction of the medial cartilage It is of course *not* a sign of an increase in the volume of the cartilage laterally by new formation of cartilaginous tissue

3 *Structural changes* in the medial lower part of the head and the region of the fovea are sometimes seen in cases of medial arthrosis with a relatively marked decrease of the floor distance but they are rarely of any significance compared with the often extensive changes in proximal arthrosis A slight flattening of the changed area has occasionally been observed

4 Acetabular protrusion is often described as an aetiological factor of coxarthrosis

Primary protrusion and Otto Chrobak's pelvis must however be distinguished from secondary protrusion

In the secondary but not in the primary form the floor of the acetabulum is thickened by secondary bone formation

In some cases of medial arthrosis the author has had the opportunity

of following the development of a typical secondary protrusion after the onset of arthrosis It would appear justified to regard the medial arthrosis as an aetiological factor of the protrusion and not the other way around The author has never seen any case of proximal arthrosis with the development of protrusion during the course of arthrosis

It seems probable that osteoporosis (or some form of osteomalacia) must be assumed as a further aetiological factor This appears to be strengthened by the observations by the author in rheumatoid arthritis (whether treated with cortisone or not)

Illusrated cases of arthrosis cum protrusion in the literature also appear to be of the medial type and to be associated with a thickening of the floor of the acetabulum It would therefore appear meaningless to calculate the frequency of protrusion in proportion to all cases of arthrosis Such a frequency should instead be calculated only relative to the number of cases of medial arthrosis Protrusion should not be regarded as an aetiological factor but as a secondary phenomenon in such cases

Anatomic Details of the Joints in Medial Arthrosis

In joints with medial arthrosis the CE angle is of normal size Occasionally it may be of borderline value i e 24–25 It should however be recollected that an irregularity in the configuration of the acetabulum can result in the measure of the CE angle differing slightly with the slope of the pelvis (Hermodsson 1947)

Even if the CE angle is of normal size the following irregularities i e deviations from normal anatomy may be seen

1 *Medial flattening of the roof of the acetabulum* This results in narrowing of the medial part of the joint space already before development of arthrosis This narrowing constitutes a source of error in the evaluation of destruction if any of the cartilage and is probably also a predisposing factor for arthrosis

2 *Accentuated curvature in the lateral part of the roof adjacent to E* This may readily lead to a false diagnosis of destruction of the cartilage

3 *Very deep acetabulum in joints with large CE angle* Here the roof is flatter than expected from the configuration of the head with consequent incongruence The joint space is wider laterally The incongruence probably predisposes to development of medial arthrosis of the joint

4 *Coxa vara* Here the term 'coxa vara' refers solely to the size of the angle of the femoral neck The present investigation is *not* concerned with coxarthrosis secondary to other diseases thus *not after* epiphyseal slipping for example It should, however be stressed that deformation due to epiphyseal slipping is often difficult to *diagnose* (both in the absence and particularly in the presence of secondary arthrosis) In such cases the diagnosis requires careful roentgen examination and experience on the part of the examiner (cf Jerre's (1950) thesis on slipped upper femoral epiphysis)

The abnormally small angle of the neck in coxa vara (irrespective of the cause) implies a disturbance of the normal distribution of the load on the hip and thereby predisposes to medial arthrosis

Coxa vara appears often to be associated with a deep acetabulum with a thin floor (possibly primary acetabular protrusion)

PRIMARY AND SECONDARY COXARTHROSIS PROGNOSIS

According to modern pathologists the changes in coxarthrosis can under certain favourable circumstances regress According to Trueta 'The osteoarthritis is a reversible condition which can be made quiescent by measures to restore the chances of survival or revival of the joint cartilage'

Judging from the literature and personal experience structural changes e g cyst formation can regress *inter alia* if the joints are rested long enough It is more difficult to understand regeneration of joint cartilage Harrison et al (1953) and Trueta (1964) however state 'Where the fibrous marrow comes to the surface at the pressure area it differentiates into a fibrocartilage which is usually degenerated but at times is almost hyaline in nature Especially in patients whose hip joints have been placed at rest or when mechanical conditions have been changed these cartilaginous outgrowths become confluent and may resurface the previously naked and eburnated bone' (It appears from the literature that pathologists support their claims on examination of cases of proximal arthrosis (cf Fig 3[1]))

Pathologists support their conclusions mainly on cases of arthrosis which have been operated especially by osteotomy Also some orthopaedists share the opinion of the pathologists and generally support their conclusions on cases that have been subjected to osteotomy

From a roentgenological point of view it should however be ob

served that an increase in the width of the joint space is as mentioned by no means always a sign of regeneration or increase in volume of the articular cartilage

Arthrosis of dysplastic joints (proximal arthrosis) is regarded by certain authors as primary arthrosis It would however be more correct to label it "secondary Strictly speaking also the medial arthrosis of the joints with a normal CE angle should be regarded as secondary if there are such deviations from the normal anatomy which must be regarded as predisposing to arthrosis

Primary arthrosis then is relatively uncommon and its prognosis is good compared with that of secondary arthrosis and particularly with that of proximal arthrosis

SUMMARY

In hip joints with a normal CE angle the coxarthrosis assumes a medial type The proximal type is to be found only in joints with subnormal angle The size of the floor distance is of great importance to the roentgenologic diagnostics of the progression of the arthrosis

The prognosis of the medial type of arthrosis is by far the best

CASES OF MEDIAL ARTHROSIS



Figure 11 S S., m le 1957



Figure 12 Same patient 1967

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SUMMARY

In hip joints with a *normal CE angle the coxarthrosis assumes a medial* type The proximal type is to be found only in joints with subnormal angle The size of the floor distance is of great importance to the roent genologic diagnostics of the progression of the arthrosis

The prognosis of the medial type of arthrosis is by far the best

CASES OF MEDIAL ARTHROSIS



Figure 11 S S male 1957



Figure 12 Same patient 1967

CASES OF MEDIAL ARTHROSIS

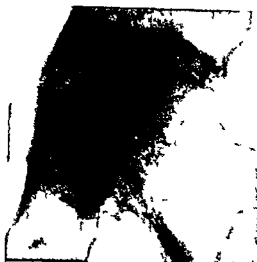


Figure 13 R. W., male, 1954



Figure 14 Same patient, 1962



Figure 16 Same patient, 1969

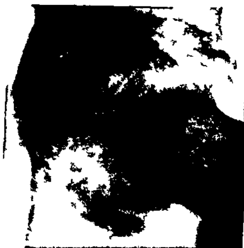


Figure 15 Same patient, 1969
Lauenstein's position

CASES OF MEDIAL ARTHROSIS



Figure 17 E T male 1969



Figure 18 Same patient 1969
Lauenstein's position



Figure 19 F F male 19 9
Right hip joint



Figure 20 Same patient 19 9
Left hip joint

CASES OF MEDIAL ARTHROSIS



Figure 21 Same patient 1967
Right hip joint



Figure 22 Same patient 1967
Right hip Lauenstein



Figure 23 K B female 1969
Left hip joint



Figure 24 Same patient 1969
Left hip joint Lauenstein

Notes to the figures
Films of the entire pelvis were used in the examination of all hip joints Frontal views and views in Lauenstein's position were taken in all cases For explanation of symbols in this Table see page 174

Patients Name sex year of birth	Rtg	Rtg symbols	Fig no	Remarks
F L. female b. 1896	1965	22 p(o+cd+db) d=11	1	Joint space clearly wider in 1967
	1967	22 p(o+cd+str+bu+db) d=13	3	
	1969	19 p(o+cd+str+bu+db+dr) d=14	3 4	
B B female b. 1896	1962	20 p(cd+o+str+db) d=12	5	hip op 1968
	1967	15 ? p(cd+o+str+db+bu+dr) d=19	6	
L. W female b 1901	1959	24 o d=10	7	
	1959	23 p(o+cd) d=10	8	
	1968	20 ? p(o+cd+str+bu+db+dr) d=13	9	
	1968	28 ? p(o+cd+str+bu+db+dr+ea) d=18	10	
S S male b. 1908	1957	33 m(o+cd) d=8	11	
	1967	37 m(o+cd) d=7	12	
R W male 1890	1954	45 m(o+cd) d=4	13	1969 beginning *of a protrusio* Bone formations *laterally*
	1962	45 m(o+cd+str) d=3	14	
	1969	45 m(o+cd+str) d=0	15 16	
E T., male b. 1904	1969	40 m(o+cd) d=8	17 18	
F F male b 1896	1959	45 m(o+cd) d=1 Coxa vara (112)	19	No other joint diseases No steroid therapy
	1959	45 m(o+cd+str) pro c. vara (105)	20	
	1967	4a m(o+cd+str) pro? c. vara (112)	21 22	
K. B., female *b 1909*	1969	45 m(o+sd+str) d=2 pro	23 24	Bone formations laterally on the head neck, and acetabulum

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Acta orthop Scandinav 41 188–198 1970

Karolinska Sjukhuset Department of General Surgery and Sodersjukhuset Surgical Department I Stockholm Sweden

TRAUMATIC DISLOCATIONS OF THE HIP

Follow Up on Cases from the Stockholm Area

LARS OLOF LAMKE

Received 23 xii 68

Traumatic dislocation of the hip is a rare injury but its incidence is on the increase because of the increasing number of traffic accidents Most doctors usually have little experience of its treatment and prognosis The object of the present study is to elucidate certain problems relating to prognosis and treatment

PREVIOUS INVESTIGATIONS

The first detailed description of traumatic dislocation of the hip was rendered by Bigelow in 1869 Since then various types of reduction and after treatment have been recommended Bohler considers bed rest for a couple of weeks after the reduction to be sufficient and in his opinion necrosis of the femoral head is a relatively uncommon complication Watson Jones recommends a hip cast for 6–8 weeks and states that necrosis of the femoral head occurs at a rate of up to 30 per cent In Sweden the after treatment has generally been as recommended by Palmer bed rest for 3–4 weeks with the leg in abduction and neutral rotation Thereafter weight bearing is gradually resumed

The largest material of traumatic dislocations of the hip was collected by Thompson & Epstein (1951) in Los Angeles It comprises 204 cases 116 of whom were included in the follow up These authors concluded that the ultimate outcome was not influenced by the time at which full weight bearing was resumed On the other hand a certain selection had taken place the most severe cases having to avoid weight bearing longest Necrosis of the femoral head occurred in about 20 per cent In Scandinavia major studies have been reported by Buus (1938) who collected 109 cases and Paus (1951) who had 76 Buus found that a difference in the duration of bed rest did not affect the therapeutic

results in uncomplicated cases In his material the incidence of necrosis of the femoral head was 8 per cent and that of nerve injury 4–5 per cent At follow up 54 per cent of the patients were symptom free In Sweden Waller (1955) in a thorough study of the dorsal acetabular fractures which so often attend dislocation of the hip emphasized the importance of surgery in reconstructing the joint surface to prevent posttraumatic osteoarthritis

In the present study it was attempted to elucidate the incidence of this injury in particular with a view to the increasing number of traffic accidents It was endeavoured also to assess the long term prognosis and to arrive at certain lines for aftertreatment especially the duration of non weight bearing

MATERIAL AND METHODS

The investigation comprises patients from the Stockholm area who sustained traumatic dislocation of the hip during the period 1945–1964 inclusive The material does not include traumatic dislocations of the hip in children under 15 years of age central dislocations i e compression fractures of the acetabulum or dislocation associated with fracture of the homolateral femoral diaphysis

The method was as follows After the case records for all traumatic dislocations of the hip had been picked out from the surgical and orthopaedic departments they were checked in the archives of the X ray departments In this way the majority of traumatic dislocations of the hip occurring during this period were included It was taken for granted that all patients had been admitted to hospital The patients then received a written request to present themselves for clinical examination Out of the 110 patients 83 (75 per cent) answered the letter but only 67 (61 per cent) could attend as 2 were at sea and 14 were living in such distant places that they did not have time or occasion for attending Nine patients had died and three had emigrated or returned to their home countries after stay in Sweden The remaining 15 patients could not be traced All the clinical examinations were performed by the author The follow up included X rays of the injured as well as of the unaffected hip In most cases Waller s oblique projection was used to assess the acetabular rim The shortest follow up period was 3 years and the longest 17 years average 6 9 years.

RESULTS

The age distribution shows a marked predominance of the young groups (Table 1) The explanation must be partly that young persons more often take part in activities likely to lead to dislocation of the hip and partly that older people are more apt to sustain fractures although fracture of the neck of the femur is not a direct alternative to dislocation of the hip In this connection it may be mentioned that one of the

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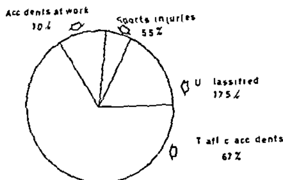


Figure Distr bution of traumatic dislocation of the hip by aetiology

oldest patients of the present material was a 71 year old woman who sustained dislocation of the hip some years after nailing of a fracture of the femoral neck The dislocation was successfully reduced and the patient was symptom free at follow up 3 years later (Figure 1) Among the causes traffic accidents predominate making up 67 per cent (74 cases) (Figure 2) Other causes were occupational in 10 per cent (11 cases) including 6 patients who fell from a height Sport was respon sible in 6 cases (5 5 per cent) The reason why sports accidents have such a small share is probably that in general a very severe trauma is required to cause dislocation of the hip The sports accidents were distributed as follows football 2 wrestling 1 tennis 1 riding 1

During the period of the study the incidence of dislocations increased quite appreciably (Figure 3) At the outset it was only 2 cases a year but during the latter part of the period it has been 10 a year

Table 1 Age distribut on in 110 cases of d slocation of the hip

Age at time of trauma	Number
15–29	43
30–44	9
45–59	26
60–85	12
Total	110

102 patients sustained posterior dislocation (93 per cent) and 8 ante rior (7 per cent) This is in quite good conformity with previous re ports Furthermore it may be mentioned that in 42 cases (39 per cent)

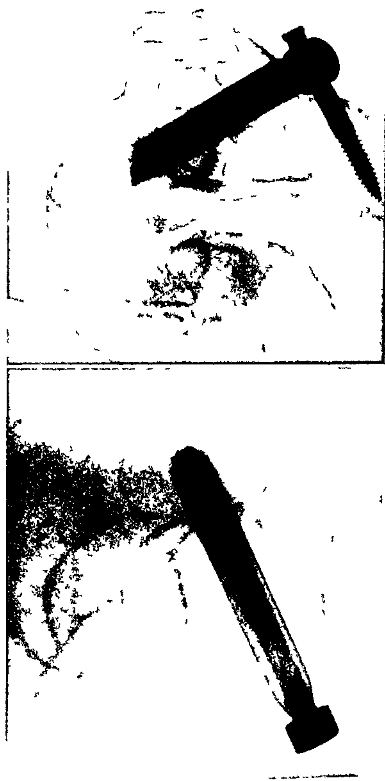


Figure 1 A 71 year old woman with a history of nailing of a fracture of the femoral neck who subsequently sustained dislocation

Group III Other primary injury due to the dislocation e g injury to the sciatic nerve avulsion of the greater trochanter

Thereafter the patients were divided into groups according to the result at follow up

Group A Good No subjective complaints or limitation of movement and no X ray signs of posttraumatic changes

Group B *Fair* Mild subjective complaints or slight limitation of movement (less than 10 in any direction as compared with the contralateral hip) or mild X ray changes The patient has not had to change his occupation

Group C *Poor* Considerable subjective complaints and limitation of movement Receiving disablement pension or has had to change his occupation Pronounced X ray changes

The analysis showed that in patients with dislocation only the prognosis is considerably better (Table 2) than in patients with associated injuries due to the dislocation Nerve damage and damage to the femoral head are particularly poor prognostic signs No patient with such damage could be assigned to the good group

Table 2 End result in different types of dislocation of the hip

Group	Type of injury	Good	Fair	Poor
I	Dislocation only	24	8	2
II	Associated injury to hip joint			
	a acetabular fracture	8	10	3
	b injury to head of femur		1	5
III	Other injury			
	a nerve injury		2	3
	b avulsion of fragment from greater trochanter	1		
	Total	33 (49 %)	21 (31 %)	13 (20 %)

Moreover it was found that the group of completely recovered patients predominates comprising 49 per cent This predominance is even more marked if we select patients with dislocation only and no injuries to other parts either In this category 64 per cent were entirely symptom free (Table 3) Mild complaints were found in 27 per cent of

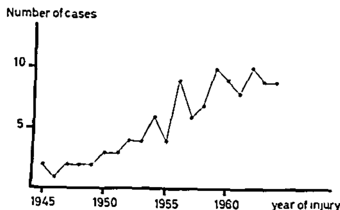


Figure 3. Number of cases with traumatic dislocation of the hip in the Stockholm area during period 1945–1964.

there was an acetabular fragment. However, most were rather small and of Waller's type 1 (fracture of the upper posterior part of the acetabulum with no or little displacement).

Considering that the great majority were traffic accidents or working accidents, it is not surprising that about half the patients had injuries to other parts also. The average stay in hospital was 19 days, longest stay 5 weeks and shortest 3 days for patients having dislocation only. The period off work was difficult to check, in particular for patients who sustained their accidents in the 1940's. Therefore no statistical analysis was performed in this respect. Most of the patients were off work for a couple of months.

FOLLOW-UP

The 67 patients included in the follow-up study had been treated as follows. Reduction had been performed in all cases and thereafter 12 *had been protected from weight bearing for less than 2 weeks, 41 for* longer than 2 weeks, 4 had been in plaster casts after the reduction and 7 had undergone operation fixing the posterior fragment to the acetabular rim. Two patients had been treated by traction and one by traction as well as operation.

In order to be able to compare the results of the various therapeutic methods, in particular with a view to the duration of non-weight bearing, the author divided the patients into 3 groups.

Group I. Dislocation only.

Group II. Associated primary injury to the hip joint, e.g. acetabular fragment or injury to the femoral head.

Table 4 Final results in different groups compared with different types of treatment

Treatment	Group I			Group II			Group III		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Reposition and full weight bearing before 2 weeks	8	2	1	1					
Reposition and full weight bearing after 2 weeks	16	6	1	[illegible]	5	6		1	1
Reposition and plaster				1	1		1	1	
Reposition and operation of acetabular fragment				1	3	1			2
Reposition and traction					1	1			
Reposition traction and operation of acetabular fragment					1				

49 per cent of our patients had completely recovered at follow up and 31 per cent had only minor complaints a minimum of 3 years after the accident The material included only 8 cases of necrosis of the femoral head i e 7 per cent This is a low incidence compared with most other series in which it has ranged from 5 to 30 per cent The explanation why this incidence varies so widely in other materials may be different radiological criteria of such necrosis and that most of the materials are rather small so that merely a couple of cases having necrosis of the head may shift the percental distribution Out of the cases with necrosis in the present material 3 had to be designated as partial fractures in the area of the head with subsequent necrosis (Figure 4) Out of the remaining cases 2 were suspected of fracture lines in the head and only 3 occurred without definite primary injury In these cases however it cannot be excluded that there may primarily have been fracture lines in the femoral head only these lines have not been visible on X rays Myositis ossificans did not occur in this material this is remarkable considering that it has occurred in most other reported series I am unable to explain this phenomenon

those with dislocation as the only injury. Re-dislocation occurred in 2 cases, necrosis of the head in 8 (7 per cent) and serious nerve injury in 5.

Table 3. Patients having dislocation of the hip as the only injury

Group	Number of patients	Per cent
Good	14	54
Fair	7	27
Poor	5	19

In order to compare the influence of the various therapeutic methods upon the results in the various groups the author divided the material by type of treatment. With a view to the duration of non-weight bearing the group with dislocation only was divided into 2 subgroups: patients who were allowed early weight bearing and patients who had late weight bearing. The limit was set at 2 weeks (Table 4). It is apparent from this table that methods using operation, traction or plaster casts have in fact given poorer results than reduction and non-weight bearing. However, it should be pointed out that these active methods were used mainly in the groups with associated injuries due to the dislocation. Moreover it must be borne in mind that these groups are too small to be compared statistically. In respect to early or late weight bearing, the group with early weight bearing even seems to show a somewhat better result than the group with late weight bearing. It is further apparent from the table that no patient with uncomplicated dislocation of the hip had been treated by the plaster cast recommended by Watson-Jones. This treatment seems to have been reserved for cases having acetabular fragments or injury to the femoral head. The use of operative treatment, in particular of the acetabular fragment, appears to have increased somewhat during recent years, presumably because of Waller's study of this group. However operative treatment does not appear to have influenced the end result to any major extent as compared with conservative treatment when considering the group as a whole.

DISCUSSION

As already mentioned the incidence of dislocations of the hip is on the increase, presumably because of the increasing traffic.

The prognosis may be said to be on the whole favourable as about

Re dislocation occurred in 2 cases of the present material This is a fairly high incidence most previous series having had no instances of re dislocation Therefore it would hardly seem necessary to expect this complication and the risk of re dislocation does not make up an indication for long lasting non weight bearing plaster cast or traction

Thus in the ordinary case without other complicating injuries to the region of the hip joint it seems sufficient to protect the injured hip joint from weight bearing for a period of up to 2 weeks

SUMMARY

This is a report on 110 cases of traumatic dislocation of the hip with a minimum follow up period of 3 years Out of these patients 67 were after examined by the author The results show that the prognosis of simple dislocation is favourable about 50 per cent of the patients being symptom free at follow up and about 30 per cent having only mild complaints The type of an associated injury in the hip joint such as injury to the femoral head an acetabular fragment or nerve damage is the most important prognostic factor It was not possible to demonstrate any definite difference between the results in patients who had short lasting and patients who had long lasting non weight bearing Therefore early weight bearing is recommended

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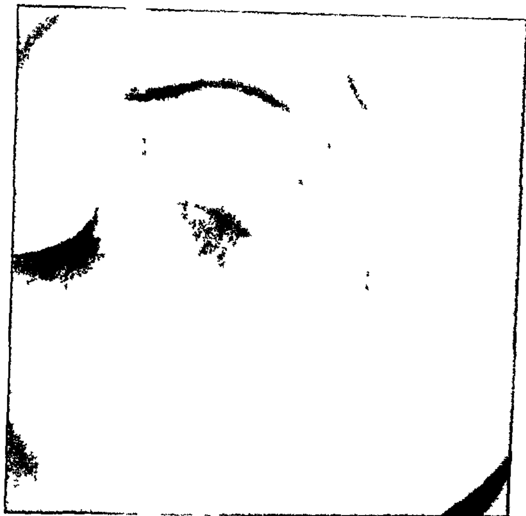


Figure 4 Head of the femur with fracture complicating dislocation

Prolonged non weight bearing seems to have predominated formerly in spite of the fact that several previous studies have hardly been able to demonstrate better results from this treatment In the present study it was found that in uncomplicated dislocation of the hip it is unnecessary to force the patient to long lasting bed rest and crutches for months This accords also with the findings of Rydell (1966) By an electrical pressure transducer applied to a femoral head prosthesis he demonstrated that lifting of a non weight bearing extended leg results in equally great pressure actions in the hip as during weight bearing From the present studies it was apparent also that it was the type of the primary injury more than the subsequent treatment which decided the prognosis

Re dislocation occurred in 2 cases of the present material This is a fairly high incidence most previous series having *had no instances of* re dislocation Therefore it would hardly seem necessary to expect this *complication* and the risk of re dislocation does not make up an indication for long lasting non weight bearing plaster cast or traction

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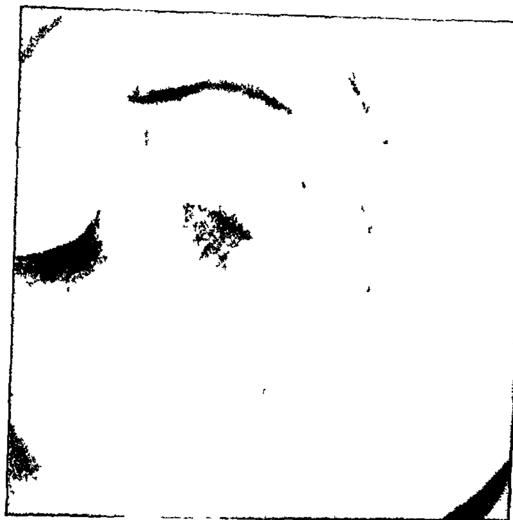


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GROWTH DISTURBANCES OF THE PROXIMAL END OF THE FEMUR

ERRATUM

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Vol 41 Fasc ? 19 0

Salenius P & Videman T Growth Disturbances of the Proximal End of the Femur An Animal Experimental Study with Tetracycline pp 199–212

The color illustrations on pages 201 204 and 208 of this article were erroneously placed

The illustration labeled Figure 2 page 201 is actually Figure 9 and should have been placed on page 208

The illustration labeled Figure 5 page 204 is actually Figure 2

The illustration labeled Figure 9 page 208 is actually Figure 5

The legends accompanying the Figures are placed upon the correct pages

MATERIAL AND METHODS

The material compri es 0 pigs 4–8 weeks old and 20 r bbits, a few weeks old. In the fir t st ge epiphyseodesis of the gre ter trochanter was performed on the

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Figure [illegible] In a longitudinal section in ultraviolet light the deposition of tetracycline is seen in the metaphysis as well as lines in the diaphysis The capital epiphyseal plate has grown new bone between it and the tetracycline deposit This is not seen on the side of the trochanteric epiphyseal plate Both the capital epiphysis and the trochanter have grown new bone also from the periosteum but this is more marked on the side of the trochanter



Figure 1 Epiphyseodesis of the greater trochanter with resulting coxa valga formation The contra lateral hip on the left

rabbits by emptying the epiphyseal plate under local anaesthetic and epiphyseodesis of the capital epiphysis was performed on other animals likewise by destroying the epiphyseal plate Before operation these rabbits were given tetracycline (50 mg per kilogram) and the same dosis after operation at 4 week intervals It was found that rabbit femurs were too small for the purpose of this investigation so the same tests were transferred to pigs Under general anaesthesia epiphyseodesis of the greater trochanter was performed in some pigs and of the capital epiphysis in others The animals were given tetracycline before operation and again afterwards The animals were killed 2–4 months after operation and results recorded both by X ray and by photographing a longitudinal section of the proximal end of the femur in ultraviolet light

RESULTS

Epiphyseodesis of the Greater Trochanter

After epiphyseodesis of the greater trochanter coxa valga formation developed in all operated animals (Figure 1) In the longitudinal tetracycline section, growth was found to be totally lacking in the region of the greater trochanter (Figures 2 3 4) The capital epiphysis had



Figure In a longitudinal section in ultraviolet light the deposition of tetracycline is seen in the metaphysis as well as lines in the diaphysis The capital epiphyseal plate has grown new bone between it and the tetracycline deposit This is not seen on the side of the trochanteric epiphyseal plate Both the capital epiphysis and the trochanter have grown new bone also from the periosteum but this is more marked on the side of the trochanter



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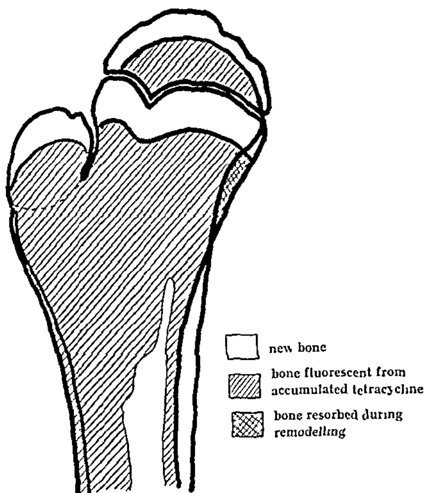


Figure 4 A schematic drawing of the changes in remodelling

ures 2 3 4 and 5) This is shown by the fact that in the epiphyseodesis specimen the tetracycline line from the diaphysis at the side of the greater trochanter continues uninterrupted upwards to the epiphyseal line whereas in a normal specimen it breaks below the trochanter (Figures 2 and 5) The same is seen in the other specimens

Capital Epiphyseodesis

After capital epiphyseodesis a typical coxa vara formation appears in the hip during growth (Figure 8) In the longitudinal sections

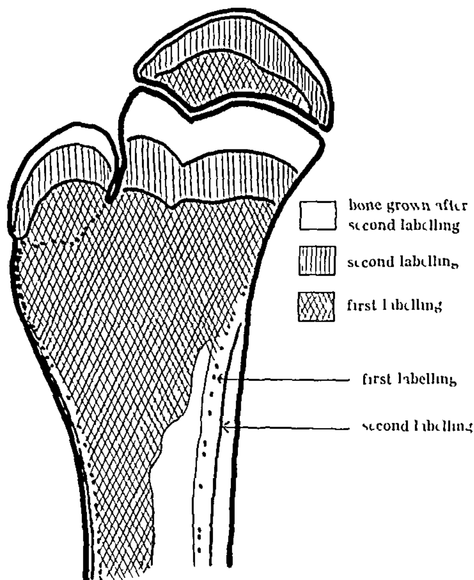


Figure 3 A schematic drawing of the changes in Figure 2

grown new bone between the epiphyseal plate and the bone marked by tetracycline (Figures 2 and 4) It was then found that both capital epiphysis and trochanter had also grown from the periosteum but the trochanter considerably more than the head (Figures 2-7)

In comparison of tetracycline cross sections from a normal hip and from the specimen in which epiphyseodesis of the greater trochanter was performed the lines of tetracycline along the diaphysis indicate that epiphyseodesis of the trochanter not only stopped growth at the trochanter but also stopped the process of remodelling resorption (Fig

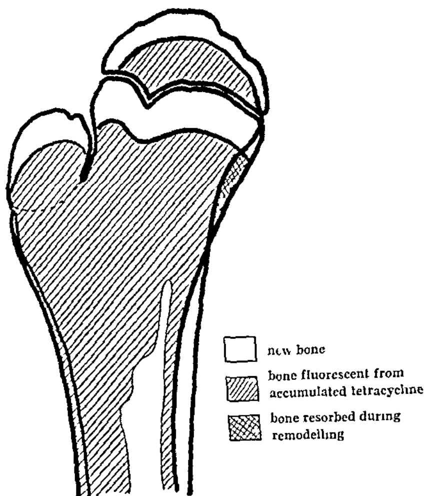


Figure 4 A schematic drawing of the changes in remodelling

ures 2 3 4 and 5) This is shown by the fact that in the epiphyseodesis specimen the tetracycline line from the diaphysis at the side of the greater trochanter continues uninterrupted upwards to the epiphyseal line whereas in a normal specimen it breaks below the trochanter (Figures 2 and 5) The same is seen in the other specimens

Capital Epiphyseodesis

After capital epiphyseodesis a typical coxa vara formation appears in the hip during growth (Figure 8) In the longitudinal sections



Figure 5 The tetracycline deposition in a normal hip If compared to Figure 9 it can be seen that the lines in the diaphysis break on both sides whereas in Figure 9 the line continues until the epiphyseal plate on the side of the epiphyseodesis

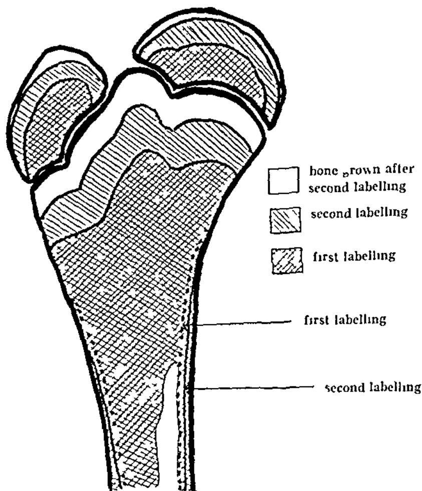


Figure 6 A schematic drawing of the changes in Figure 5

marked by tetracycline it is observed that the trochanteric epiphyseal plate causes growth on the side of the trochanter in the normal manner whereas the destroyed capital epiphyseal plate has not caused growth (Figures 9-11) Comparison with the normal hip shows that resorption remodelling has also been disturbed in addition to growth Further the neck of the femur has clearly shortened and the trochanter grown far above the head The head has become irregular and broad



Figure 8 The tetracycline deposition in a normal hip If compared to Figure 9 it can be seen that the lines in the diaphysis break on both sides whereas in Figure 9 the line continues until the epiphyseal plate on the side of the epiphyseodesis



Figure 8 In this animal epiphyseodesis of the capital epiphysis was performed which resulted in coxa vara formation The normal hip on the left

and CDH In sections marked by tetracycline it was observed that as the epiphyseal plate of the greater trochanter continued its growth producing an area of bone free from tetracycline below it a similar area also developed at the tip of the trochanter showing that the latter grows considerably from the periosteum also

Capital epiphyseodesis caused formation of a short neck of the femur A malformed femoral head appeared at the same time In addition to cessation of the growth in the epiphyseal plate it is apparent from tetracycline lines in the diaphysis that remodelling resorption in the peripheral part of the epiphysis has also ceased This resorption is indispensable in the upward growth of the bone in order to preserve the normal form of the proximal end of the femur (Enlow 1963) It is thus evident that growth and resorption are interconnected in the function of the epiphyseal plate

In connection with epiphyseodesis of the greater trochanter typical coxa valga formation with corresponding cessation of resorption and growth on the side of the trochanter were observed while on the side

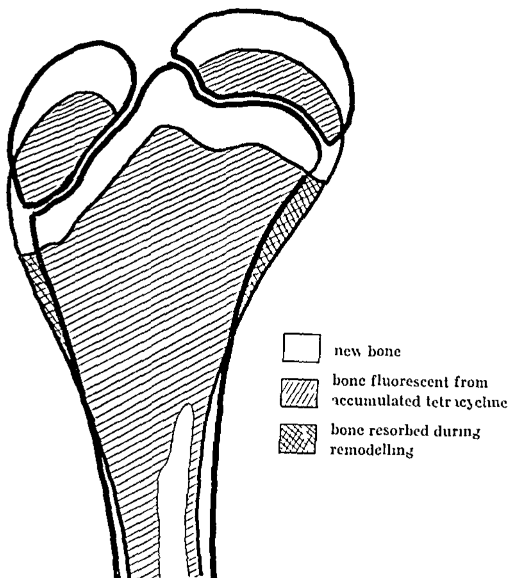


Figure 7 A schematic drawing of the changes in remodelling

DISCUSSION

In the present study disturbance of the epiphyseal plate was caused artificially using the pig and rabbit as experimental animals Both the epiphyseal plate of the greater trochanter and the capital epiphysis were destroyed in different animals Thus the coxa vara and coxa valga formations previously observed in the series of Compere (1940) and Laurent (1959) were produced After capital epiphyseodesis a typical coxa vara was then produced This is often observed in clinical work in connection with Legg Perthes Calve disease congenital coxa vara

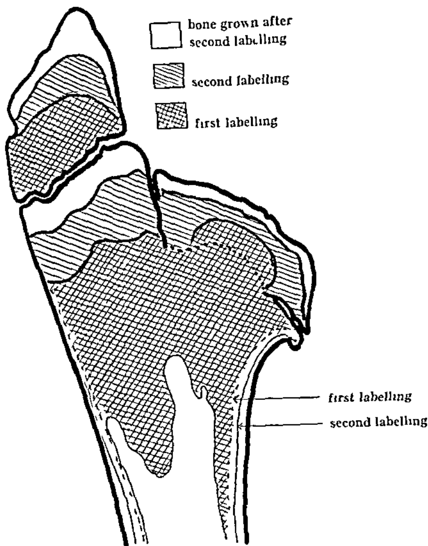


Figure 10 A chematic drawing of the changes seen in F gure 9

of the head growth continued normally Resorption however was clearly less prominent than increase of the growth This is obviously necessary because the head and neck grow in all directions with the normal growing animal In normal specimens strong periosteal growth at the tip of the greater trochanter is also clearly in evidence This ex



Figure 9 In a longitudinal section of the hip seen in Figure 6 the deposition of tetracycline can be seen in ultraviolet light On the side of the greater trochanter the line in the diaphysis indicates a resorption remodelling process while on the side of the capital epiphysis the line continues to the epiphyseal plate No growth but also no resorption has taken place on this side

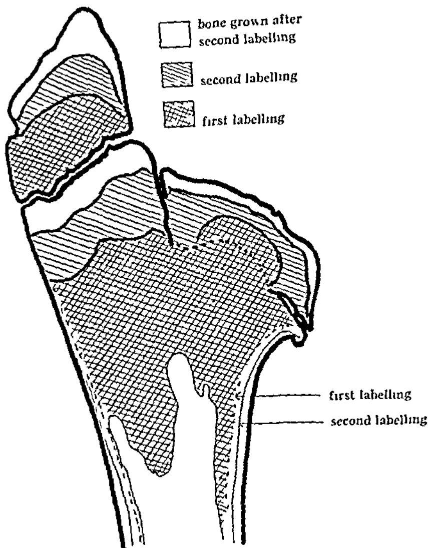


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CONCLUSIONS

From the experiments performed on pigs the following observations were made (1) After epiphyseodesis of the greater trochanter coxa valga formation developed The growth continued on the side of the capital epiphysis (2) The resorption ceased on the side of the epiphyseodesis whereas it continued on the side of the capital epiphysis This was evident from the tetracycline lines in the diaphysis (3) After epiphyseodesis of the capital epiphysis coxa vara followed The growth ceased on the side of the epiphyseodesis and continued on the side of the greater trochanter (4) The resorption also ceased on the side of the epiphyseodesis but continued on the side of the greater trochanter (5) The greater trochanter and the capital epiphyses also grow from the periosteum but the greater trochanter more than the capital epiphysis

SUMMARY

The authors performed experimental epiphyseodesis on the epiphyseal plates of the proximal end of the femur in rabbits and pigs After trochanteric epiphyseodesis a typical coxa valga formation was observed and after capital epiphyseodesis a coxa vara formation The situation in the hip of the animal at the moment of epiphyseodesis was marked with tetracycline and later the development of growth of the proximal end of the femur was followed by further doses of tetracycline It was then observed that both the head and the greater trochanter grow to some extent from the epiphyseal plate and the periosteum but the trochanter considerably more from periosteum than the head With the cessation of growth after epiphyseodesis the resorption remodelling also ceases near the particular epiphyseal plate Resorption is evidently less prominent that was previously thought The proximal end of the femur grows in all directions at the same time as it grows upward

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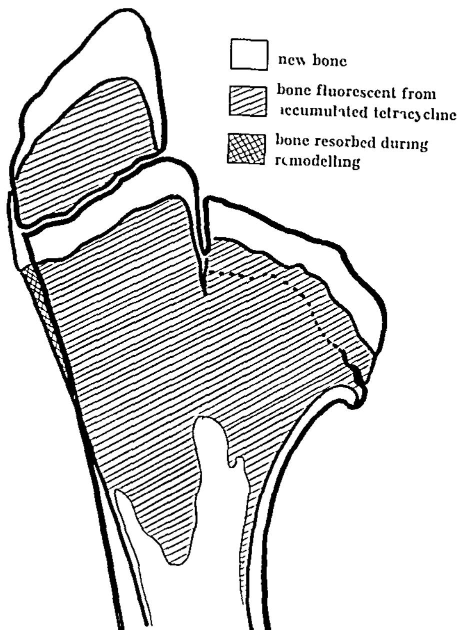


Figure 11 A schematic drawing of the changes in remodelling

plains the fact that despite epiphyseodesis of the greater trochanter in certain cases of coxa vara considerable growth still occurs especially at the end of the growth period at the tip of the greater trochanter (Langenskiold & Salenius 1967)

Trochanteric epiphyseodesis has been used as a treatment and for prevention of coxa vara in children after Legg Perthes Calvé disease and in some other cases

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SUMMARY

The authors performed experimental epiphyseodesis on the epiphyseal plates of the *proximal end of the femur in rabbits and pigs* After trochanteric epiphyseodesis a typical coxa valga formation was observed and after capital epiphyseodesis a coxa vara formation The situation in the hip of the animal at the moment of epiphyseodesis was marked with tetracycline and later the development of growth of the proximal end of the femur was followed by further doses of tetracycline It was then observed that both the head and the greater trochanter grow to some extent from the epiphyseal plate and the periosteum but the trochanter considerably more from periosteum than the head With the cessation of growth after epiphyseodesis the resorption remodelling also ceases near the particular epiphyseal plate Resorp*tion is evidently less prominent that* was previously thought The proximal end of the femur grows in all directions at the same time as it grows upward

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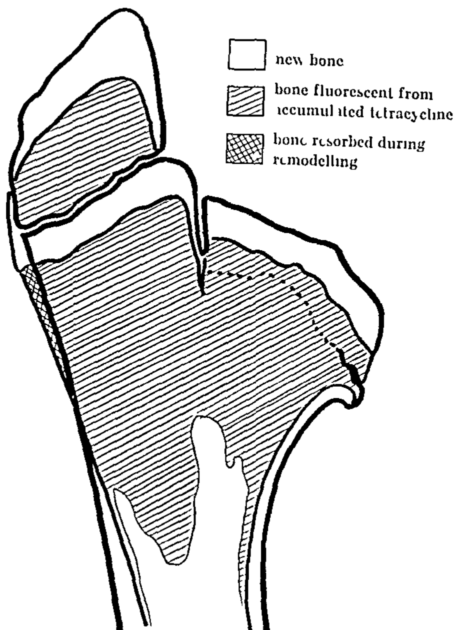


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RESECTION OF THE METATARSOPHALANGEAL JOINTS IN RHEUMATOID ARTHRITIS

HÅKAN BRATTSTRÖM & MERETE BRATTSTRÖM

Received 26 iii 69

The surgical treatment of depressed metatarsal heads with accompanying painful conditions in the forefoot has been discussed in several articles These are without exception marked by great enthusiasm for the results gained but this in the main seems to be based more on general impressions than on large follow up series (Hoffmann 1911 Key 1950 Clayton 1960 1963 Stamm 1964 Preston 1968) The follow up series reported have been small (Fowler 1959 Lidstrom 1961 Schultz 1968)

The object of the present work is to report the results from a large group of patients with the same basic disorder rheumatoid arthritis

The problems were (1) the patient s concept of the value of the operation (2) the dependence of the results of surgical methods (3) possible relation between the result of the operation and the status of the illness (E S R) duration etc and (4) complications

Rheumatoid arthritis begins as synovitis most often in the small joints of the hand and the foot Destructions and deformities appear in the fore foot if the arthritis progresses The usual changes are hallux valgus and bunion depressed metatarsal heads with painful corns in the sole and various degrees of cock up deformities of the four lateral toes In some patients the small toes are subluxated or luxated on the dorsal aspects of the metatarsal heads (Figure 1 B) Both the metatarsophalangeal joints (MTP joints) and the PIP joints can show varying degrees of involvement by the rheumatoid arthritis from slight synovitis to total joint destruction and/or ankylosis These deformities give pain on a mechanical as well as on an arthritic basis whether or not the rheumatic disease is active

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cial Insurance Board therefore patients with disability pensions and those more than 65 years of age are practically excluded from treatment there

During the mentioned period 89 patients were operated on 4 died before the follow up investigation The material thus includes 85 patients with 138 operated feet

Further data concerning the material are given in Tables 1 and 2

All the patients have a definite rheumatoid arthritis according to ARA criteria and are classified under Steinbrocker s roentgenological criteria as belonging to Group 3 or 4 All had pronounced foot symptoms in the form of loading pain recurrent callosities with a tendency to infections and great difficulties in fitting shoes For a few foot troubles were the sole indication for hospital treatment

Table 1 138 operated feet

	Male	Female	Total
No of patients	18	67	85
No of feet	28	110	138

Table 2 138 operated feet

Minimum observation time	18 mths
Mean observation time	30 6 mths
Mean duration of disease at operation	14 6 yrs
Mean age at operation	50 2 yrs
Mean E S R at operation	46 8 mm/h
Steroid treated > 1 year during period of disease	52 feet

Table 3 Number of operated feet per year during the study period

					Not included in the material	
1962	1963	1964	1965	1966	(1967	1968)
17	22	19	40	40	(42	25)

OPERATION INDICATIONS

Operation was proposed following a failure of conservative treatment when the patient had both pronounced subjective complaints and destruction of one or more MTP joints with dorsal subluxation of the basal phalanges In the absence of destruction patients were managed

Pain arises from shoe pressure on the depressed metatarsal heads or the dorsum of the first PIP joint (Figure 1 B) This may cause great difficulties in walking The patient cannot use his toes at take off in gait, and he even tries to avoid loading on the fore foot This gives a typical heel walk Each step is painful and it is impossible to wear shoes, in the most advanced stage, the patient is totally unable to walk

The unphysiological walk in turn, unfavourably affects the loading on knee and hip joints

Especially patients who also have arthritis in the talocrural joint can experience difficulties If the arthritis there forces the patient to walk on his toes the above mentioned heel walk is impossible and the weight must be put on the fore foot

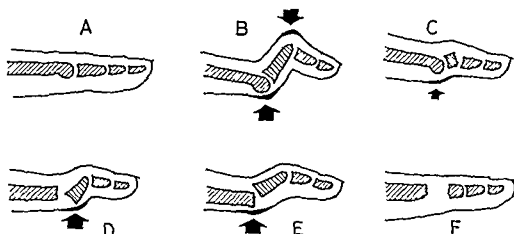


Figure 1 A A normal toe B A toe deformed by rheumatoid arthritis the basal phalanx has luxated up onto the dorsal side of the metatarsal head and corns are formed at the arrows C An ordinary hammer toe operation there is still a risk of pressure under the metatarsal head D Recurrence after metatarsal head resection the basal phalanx presses against the sole E Recurrence with other mechanism the basal phalanx has luxated up onto the dorsal side of the metatarsal stump and forces it against the sole F The skeleton after a joint resection (note the bevelled edge on the metatarsal stump)

OWN MATERIAL

We investigated those patients who during 1962–1966 were surgically treated in the Orthopaedic Clinic in Lund for depressed metatarsal heads in one or more of the four lateral toes All the patients had been hospitalized at the Rheumatology Clinic which means that the material is to some extent selected This Clinic is operated by the National So

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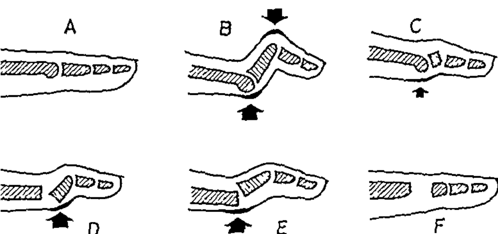
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with support, injection treatment or synovectomy We have not operated upon even badly deformed feet if the patient has had no complaints or if involvement of hip or knee has prevented walking

The so called partial phalangeal resection (Figure 1 C) has not usually been thought sufficient instead an operation on the metatarsal joint has been indicated It is these latter operations that are dealt with in this article

Activity of the disease as shown by a high E S R or current cortisone treatment was not held to contra indicate operation

Many sources have suggested that the patient s co operation is necessary in all rheuma surgical operations and that a reluctant patient is an absolute contra indication for surgery This ruling has some exceptions in our experience In operations for forefoot disorders the results are so good and the patient s co operation is of such slight importance that some persuasion is justifiable

Pressure sores on the sole have sometimes called for a few days of pre operative skin care and avoidance of weight bearing but have never prevented the operation

OPERATION METHODS

Hoffman (1911) was the first to describe these operations He removed all five metatarsal heads by a plantar incision his method is also recommended by Campbell (1963) Clayton (1963) Dybowski (1967) and Preston (1968) resected the metatarsal heads as well as the base of the basal phalanx on all five toes Fowler (1959) and Milch (1964) however resect the base of the basal phalanx and then shape the metatarsal head and remove that part facing the sole of the foot Fowler made an oval excision of the plantar skin All these authors are radical in that they recommend operating on all four small toes even if only one or two give symptoms (usually the big toe must also be treated) Thompson (1937) and Key (1950) recommended a more selective surgery by treating only the joints that showed symptoms Lidstrom (1961) suggested resection of the second third fourth metatarsal heads as routine Fowler (1959) Lidstrom (1961) and Dybowski (1967) used plaster after the operation Preston (1968) and Campbell (1963) fixed the position during the first postoperative period by drilling a Kirschner wire through the toe skeleton up into the corresponding metatarsal bone Both plantar and dorsal incisions were used most authors use a separate incision for the big toe

Our operations were performed in a bloodless field under lumbar



Figure 2 Development of operation methods A Single metatarsal head removed B Metatarsal heads 2 3 and 4 removed routinely C Joint resection in all 4 lateral joints possibly also in the big toe This is the present method Note the stump end form an even arc

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The first group (metatarsal head resections) was followed up in 1965 and 1967 the second (joint resections) in 1967 and 1968 In addition the majority of patients were seen when they attended for routine follow up examination a particular effort being made to investigate those patients who reported dissatisfaction with the operation or worsening of the condition between the two follow up investigations

We asked about ability to walk pain in toes and fore feet (chiefly scar pain) numbness in the toes whether they used a support or orthopaedic shoes and about the tendency for hallux valgus Finally the patient was asked to express his opinion of the operation as excellent good fair or poor

Table 4 shows the results in the entire material

Table 4

Result	No of feet	Observation time (mths)
Excellent	65 (47 %)	31
Good	38 (28 %)	31
Fair	17 (12 %)	31
Poor	18 (13 %)	28

No patient who classified the result as poor thought he was worse than before the operation

No relation between the results and the length of the observation period seemed to exist

The patients who had been given steroid treatment for more than 12 months during any period of the disease represent 52 feet (38 per cent) and the number treated with cortisone in "fair and poor groups is 17 (78 per cent) This over representation of cortisone patients in the failures can be explained by cortisone most probably having been given to those who had the most severe rheumatoid arthritis

No certain influence on the activity of the disease—expressed by E S R in the various result groups—was obtained (Table 5)

Table 5

	Excellent+good	Fair+poor
Mean E. S R.	50 2	45 2
Mean duration of disease	14 5	14 7
Mean age at operation	50 0	50 3

or general anaesthesia If both feet were to be operated, they were usually treated at the same operative procedure In 128 feet the operations were performed by an experienced orthopaedic surgeon All patients were operated through plantar transverse incision immediately distal to the prominences of the 4 lateral metatarsal heads If the big toe was operated on, it was done through a separate medial incision

Flexor tendons nerves and vessels were retracted where necessary although they were usually found to be displaced to the side of the metatarsal heads The metatarsal head was snipped off, and the plantar aspect bevelled to present a smooth weight bearing surface In the first operations only joint heads showing symptoms were removed usually No 3 (Figure 2 A), or sometimes all three middle joint heads (Nos 2, 3 and 4) irrespective of whether or not all gave symptoms (Figure 2 B) This later procedure follows Lidstrom s recommendation

In connexion with a follow up investigation in 1965 we found several patients with recurrence in operated joints or pain under non resected heads, we therefore changed to a more radical method and resected the entire joint i e both the metatarsal head and the base of the basal phalanx and did this in all 4 small toes irrespective of whether the patient had symptoms in all of them (Figure 2 C) The plantar aspects of the resected ends were bevelled to provide a smooth weight bearing surface We attempted to get the five metatarsal bones to form an even arc after the operation with No 1 and 2 of about the same length and thereafter a gradually decreasing length laterally (Figure 2 C) This arc is easily verified by palpation from the dorsal side The big toe was not operated on routinely unless there was a deformity (hallux valgus) as well as subjective complaints We then either operated according to Keller or made a joint resection as was done on the small toes on occasion only an exostosis chiselling was carried out The patients were given a plaster of paris shoe with which we tried to hold together the fore foot and to straighten the big toe The plaster of paris was split After one week a heel was added and the patient was allowed full weight loading Three weeks after the operation the plaster of paris was removed and the patient was recommended to use a support for at least six months

RESULTS AND DISCUSSION

Since the patients subjective complaints were the main indication for operation we thought it reasonable to assess the results by means of a questionnaire which was sent to each patient on two occasions

The best results however are in the last group where all four lateral joints—that is both the base of the proximal phalanx and the metatarsal head—were resected only 1 poor out of 78 operated This patient was a 43 year old woman who complained of scar pain and diffuse ache in the fore foot

These results argue strongly in favour *of the more radical operation*

COMPLICATIONS

In 1967 1968 and 1969 approximately 300 feet have been operated on using a plantar incision which some authors warn against as giving greater risk of infection and scar pain Of these 300 feet 5 developed a slight necrosis of the skin or an infection without any delay in healing time One patient developed a serious infection in one foot which kept her bedfast for 3 weeks *but the functional end result was excellent Out of the 138 feet in this investigation only one patient complained of scar pain* (see below)

We are thus quite satisfied with the plantar incision which gives a good approach to the joints and results in few complications

FAILURES

Twenty five *cases were regarded as failures These fell into three main* categories (1) patients who became worse between the investigations 1965 and 1967 7 feet (2) patients who were re operated before investigation 1967 13 feet and (3) patients who were classified as poor in 1967 but were not re operated 5 feet

Subjective complaints in these 25 feet were analysed in more detail The results are shown in Table 7

Table 7 Failures 25 feet

Complaint	No	Remarks
Hallux valgus	15	1st joint not operated
Painful corns under *operated joints*	19	All had only head re ection in some the re ceted metatarsal b ne pro *truded in front of the other* 4 had lack of dorsiflexion of the ankle
Painful corn under non operated joints	15	Mostly 5th joint
Scar pain	1	

Nor did the duration of the disease (14 5 and 14 7 years) or the age of the patient seem to play any role for the result (Table 5)

However if we distribute the material with regard to operation methods another picture emerges (Table 6 and Figure 3)

Table 6

	One or two heads resected	Heads 2 3 and 4 resected	Joints 2 3 4 and 5 resected	Total
Excellent	3	22	40	65
Good	0	8	30	38
Fair	1	9	7	17
Poor	5	12	1	18
Total	9	51	78	138

In the groups with one or two heads resected the poor results dominate (5 out of 9) in the group Heads 2 3 and 4 resected the good results dominate (30 excellent or good out of 51)

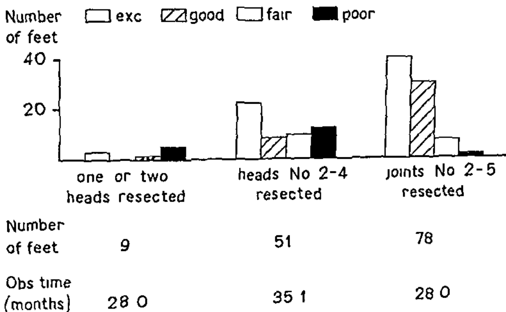


Figure 3 The operation results distributed according to different methods See text

exceptionally heavily which causes a *recurrence* Painful corns under non operated joints need no comments The patient with scar pains is the only "poor in the group with joints 2 5 resected

SUMMARY

In 85 patients with rheumatoid arthritis 138 feet were operated on for deformity and pain in the MTP joints 2–5 *If only* single metatarsal heads are removed the results are poor (5 out of 9 operated) they are better if heads 2 3 and 4 are resected routinely but best if the *entire joint* (both metatarsal head and the base of the phalanx) is removed in all small toes (1 poor out of 78 operated) Plantar incision results in few complications

The results do not seem to depend on age of the patient or the activity and *duration* of the disease

Of the patients 16 per cent whose big toe was not primarily operated developed hallux valgus

The causes of failure were pain under remaining metatarsal head (15 cases) recurrence (12 cases 4 of these had inadequate dorsiflexion of the talocrural joint) and scar pain (1 case) The causes of recurrences are analysed

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Of these 15 feet were re operated 11 are now excellent or good, 4 still poor

Table 7 calls for some discussion Of 138 feet 15 developed symptoms of hallux valgus in the operated foot this occurred in those feet (95) where no operation on the big toe was performed on the first occasion This is 16 per cent of the cases and we do not consider this complication frequency to justify the big toe s being routinely included in the operation, as proposed by some authors (Hoffman 1911, Fowler 1959 Milch 1964) especially as an intact big toe aids in walking Painful corns under operated joints can be explained partly by reference

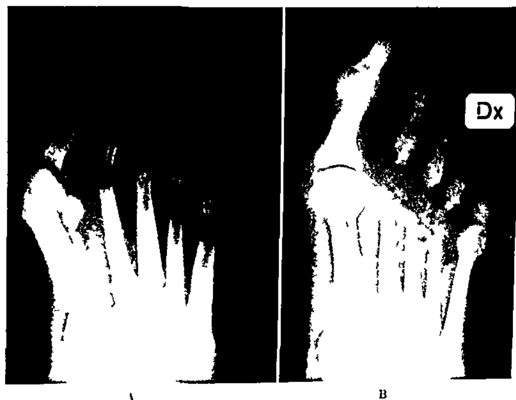


Figure 4 A Recurrence because of protruding stump end on 3rd metatarsal bone B Poor result due to pain under the 5th metatarsal head which was not removed Slight hallux valgus with pain

to Figure 1 D and E partly by in some cases the surgeon not making the resected metatarsal bones form an even arc but by letting one of the bones protrude (Figure 4) Lack of adequate dorsal flexion in the ankle joint can compel the patient to load the metatarsal bone stumps

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